Corrosion

devoted entirely to
CORROSION
research and control

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The Editorial Review Committee and the Editor of Corrosion welcome the submission of technical articles on corrosion regardless of their length or content.

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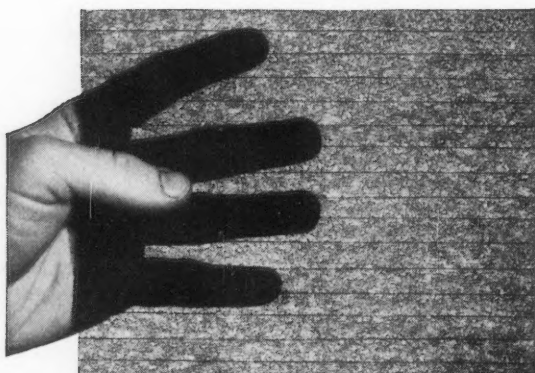
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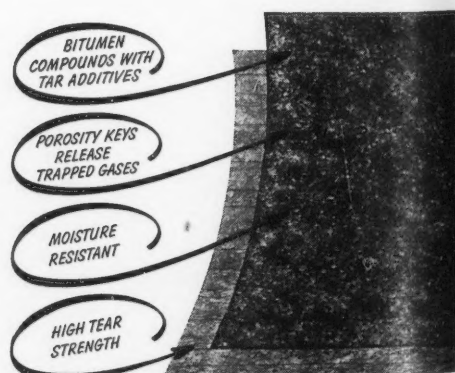
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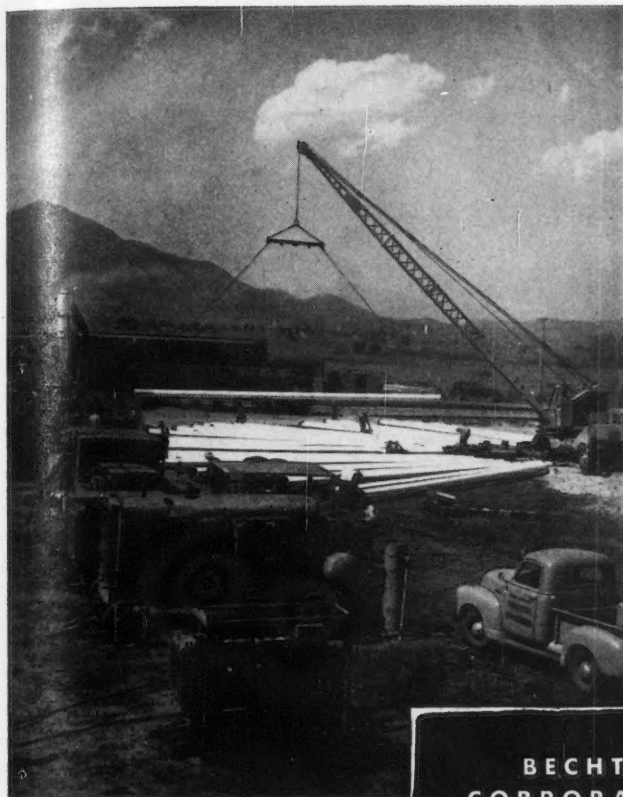
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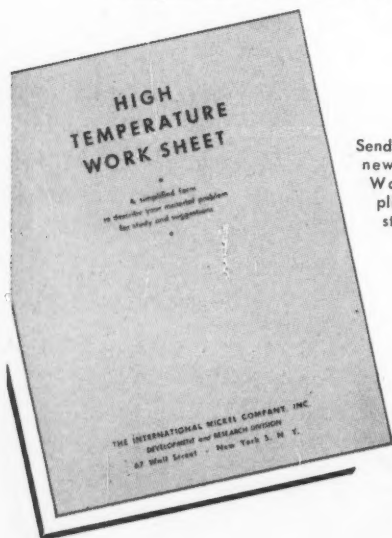
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(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

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Extraneous Currents Noted
On Large Transmission Pipe Line System

By NORMAN J. ALLISON* and WM. E. HUDDLESTON**

DURING A RECENT survey of cathodic protection requirements for a 1128-mile large diameter pipe line, it was noted that a very unusual stray current condition prevailed over the entire pipe line.

Stated briefly, a strong component of direct current was observed to flow with a behavior similar to the general run of pipe line stray currents that originate from electrified railway systems. The current would fluxuate in magnitude and direction, the usual amount of current being between 1 and 3 amperes but frequently attaining values greater than 4 amperes, and with momentary peaks of more than 5 amperes.

Variations in current flows were accompanied by corresponding variations in pipe-to-soil potentials, which would usually range from 1.5 volts negative to 0.6 volt "positive." At times the stray current surges were sufficiently strong to completely reverse DC loads that were being applied to the pipe line in the course of conducting preliminary cathodic load tests.

The presence of such extraneous currents could not be accounted for by the usual explanations, for:

1) most of the points of observation were hundreds of miles removed from any electrified railway systems;

2) welding operations were not being performed on the line at the time our observations were made;

3) the pipe line was sectionalized by insulated flanges, which would prevent the inflow of current from commonly known sources.

Since the source of the stray currents could not be accounted for (except possibly for the association with magnetic disturbances that are commonly accompanied by sun spot activity and/or similar phenomena) the question arose as to the efficacy of cathodic protection for suppressing electrolytic action that might occur at points where these stray currents discharge from the pipe.

A number of field observations were made that disclosed the following facts:

1) the fluxuating pipe-to-soil potentials within the spread area can at once be stabilized to steady protective values by the application of a cathodic load;

2) while stray currents may continue to collect on the pipe line within and/or outside of the spread area and flow along the line in conjunction with the cathodically applied current, apparently no stray current will leave the pipe within the spread area because the pipe line never "swings positive" in polarity with respect to the surrounding soil in this area.

Apparently, then, the use of cathodic protection or "forced electrical drainage" will facilitate complete protection for the pipe in the same manner that protection is obtained against stray currents that originate from the more commonly known sources.

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The Mechanism of Scale Formation On Iron at High Temperature *

By B. W. DUNNINGTON,[1] F. H. BECK[2] and M. G. FONTANA[3]

Introduction

MODERN APPLICATIONS in jet engines and gas turbines require metals that will successfully resist extreme temperature conditions. Scaling in the oxidizing atmospheres that are used in these and other high temperature applications is a problem of prime importance. In order to design alloys with satisfactory oxidation resistance the metallurgist needs, among other things, a knowledge of the rates and mechanisms of oxidation of the pure metals. Many accurate rate measurements are available for a variety of useful metals. Information on mechanisms of oxidation is still in an embryonic stage.

Investigations conducted in an attempt to explain mechanisms are frequently studies of weight change with time.[1,2,3] Recently several investigators have studied oxide growth by microscopic methods.[4,5] One of the main purposes of this investigation was a comparison of the two above procedures. Weight measurements result in an averaging over the entire surface. Microscopic examination may be made at a particular point so that if one section is reacting differently from another, this may be noted and measured.

In addition to comparing rates derived by the two different methods, microscopic examination has revealed a series of new oxide structures and modes of occurrence.

Literature Survey

There is general agreement that the formation of an oxide layer is a diffusion process. The theoretical treatment of Wagner[6] permits evaluation of the rate constant of oxidation from certain crystal properties. Usually these values are not known so that it is still necessary to actually run oxidation tests and measure the rates. However, several systems have been investigated[6] sufficiently to demonstrate that Wagner's treatment is correct. The oxides are composed of ionic crystals in which the components (anions, cations and electrons) diffuse as charged particles.

Diffusion across the oxide layer forming on a pure metal requires a concentration gradient. This means that the oxide must vary from the stoichiometric composition, even though no variation is detectable by existing analytical means. Wustite (FeO) is a metal deficient lattice and may exist with several

Abstract

A new mechanism of high temperature oxidation of iron is proposed. Diffusion of lattice vacancies in the iron is shown to influence the type of oxide that forms. It was found that with thin specimens an adherent film grew on one side and a loose film on the other. The adherent film followed the parabolic law. The loose film grew in a pseudo-linear manner. The formation of these two types of films is shown to be necessary from consideration of diffusion of iron through the metal and oxide lattices. Applying the same principles to large specimens it is shown that a different kind of oxide layer forms which was observed by Pfeil.

Photographs of magnetite slowly cooled from a high temperature indicate that a plate-like precipitate of Fe_2O_3 forms on the [111] planes of the magnetite.

A brief study was made of blistering. It is demonstrated that superficial blisters form on heating in air and photographs show the later positions of the blisters as the oxide layers grow thicker.

percent of the iron sites vacant.[7] Magnetite (Fe_3O_4) is also a metal deficient structure but has a smaller range of variation than wustite. Neither of these two oxides exist with greater than the stoichiometric amount of iron. Hematite (Fe_2O_3) is an oxygen deficient structure but no range in composition is detectable.[8]

The diffusion process may be assumed to be due to the movement of vacant lattice sites, or in some cases, not considered here, interstitial movement of ions. If only vacant cation sites exist then only cations will be expected to diffuse. On this basis, FeO and Fe_3O_4 should diffuse only iron and Fe_2O_3 should diffuse only oxygen. Birchenall[9] has recently measured the diffusion coefficients of the components of these compounds. His work supports the considerations above.

Various investigators have reported on the appearance of the oxide layers. Pfeil[10] demonstrated that the surface of metal retreats during oxidation. The area between the original and final positions of the iron is occupied by a loose agglomeration of oxide (herein referred to as the "Pfeil layer"). This work was on specimens 1/2-inch in diameter. Others[4,5,11] have studied polished cross-sections in which three continuous coherent layers appeared with the FeO directly in contact with the iron. Most of that work was done on fairly thin sheets or thin wires. The importance of the difference in occurrence of the oxides on large and small specimens has not previously been mentioned.

Apparatus

All of the oxidation tests described below were run in the vertical tube furnace illustrated in Figure

2

1. This equipment with certain improvements is essentially that previously described.[2] Gases passed into the furnace were dried as indicated. Any residual oxygen in the argon was removed by passing over hot magnesium turnings. The valves between the drying train and furnace permitted routing the gas through the furnace tube in either direction. Temperature was controlled to within ±10 degrees F (5 degrees C).

Continuous weighings were made in certain tests by use of the analytical balance set directly above the furnace tube. There is a moveable Pyrex extension on the upper end of the furnace tube which may be raised far enough to insert the sample. The specimen is hung on a hook at the end of a platinum wire. The Pyrex tube and furnace tube is connected by a ground bevel joint. After assembly it was sealed by wrapping with electrical Scotch tape. Hardness measurements were made on a Bergsman microhardness tester.

Experimental Procedure

The majority of these experiments were conducted on Armco iron sheets provided by Westinghouse Electric Corp. through Dr. J. K. Stanley. This material was received rolled to size and was stress relieved by holding for one hour at 1400 degrees F (760 degrees C). Impurities present in the material are:

Total Carbon	0.028 Wt. %
Manganese	0.019
Phosphorus	0.007
Sulphur	0.031
Silicon	0.006
Nitrogen	0.007

Specimens 2 cm square were cut from a sheet 0.16 cm thick for the microscopic work. Specimens used in the continuous weighing experiments were 3.80 x 10.25 cm cut from the same 0.16 cm sheet. The wire specimens were 2 cm lengths of 0.8 mm iron wire. Composition of this wire was approximately the same as that of the Armco iron sheets. All specimens were polished by hand with 280-grit silicon carbide paper, followed by 500 grit. The surface was then cleaned with 20 percent HCl, washed in acetone and dried before oxidation.

Manipulation of the furnace was arranged so that the specimen was not in contact with oxygen until it reached test temperature. After having been sealed in the furnace the specimen was held in the cold zone while the entire system was flushed with tank argon from which oxygen and water vapor had been removed by suitable purifying trains. When the system was completely flushed the specimen was lowered into the constant temperature zone. Once the specimen was up to temperature, dried oxygen was sent through the furnace tube and the test started. At the end of each test the specimen was quickly raised into the cold zone, where it cooled to below 300 degrees F in less than one minute.

In the case of continuous weighing tests, the platinum wire passed to the balance through a 1/16-inch hole in a thin Teflon disk on the top end of the Pyrex extension. Arrangements were made to move the disk without disturbing the seal, so that the wire could always be centered and binding prevented.
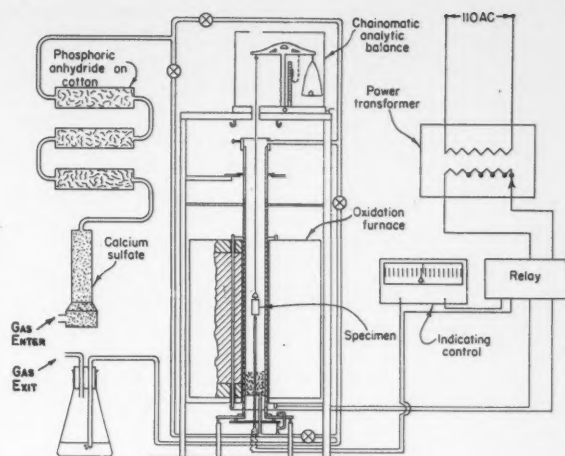
Figure 1—Experimental oxidation apparatus with controlled atmosphere.

Contamination due to diffusion of air in through this orifice was successfully prevented by running at least four liters of gas per minute vertically through the 2-inch diameter furnace tube.

Metallographic mounting and polishing of the oxidized specimens was the most difficult procedure to establish. Successful mounts were made both in low temperature casting resins such as used by Stanley,[4] and in Woods metal. Contamination of polishing wheels discourages the use of the latter.

The polishing method finally settled upon consisted of three steps: 1) Rough polishing-dry grinding on a 280-grit belt grinder down to the desired cross-section followed by wet hand grinding on 280 silicon carbide. Extreme care is necessary in this step. 2) Intermediate Polishing—wet polishing on a rapidly rotating wax wheel using first a soap solution of 3F silicon carbide and then of alpha alumina. 3) Final Polishing—not critical, may be either on wax or cloth and with a variety of polishing agents. Al_2O_3, Fe_2O_3, and MgO were all excellent. Use of a deep piled cloth tends to round the edges of small voids.

Etching was accomplished with 20 percent HCl. This solution attacks the oxide in the decreasing order FeO-Fe_3O_4-Fe_2O_3.

Results and Discussion

Measurement of Oxide Thicknesses

The thickness of FeO and Fe_3O_4 were measured from a series of tests at 2000 degrees F (1090 degrees C). Fe_2O_3 thicknesses cannot accurately be determined because the layer is rounded off during polishing. Careful study with the microscope reveals that the thickness of Fe_2O_3 increases with time, but it was impossible to record it photographically because of insufficient depth of focus. A method of coating the oxide with some hard material must be developed before precise measurements on the outer layer will be feasible.

A plot of thickness vs. time is given for FeO and
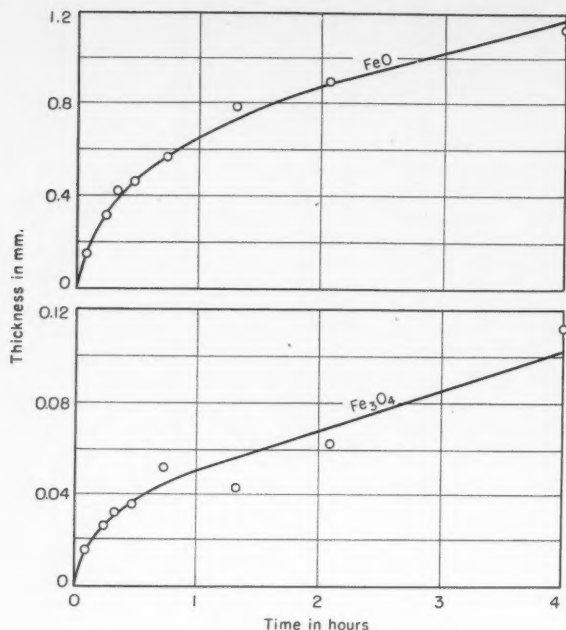
Figure 2—Thickness measurements of adherent oxide films on Armco iron at 2000 degrees F (1090 degrees C) in pure oxygen. Measurements from photomicrographs.
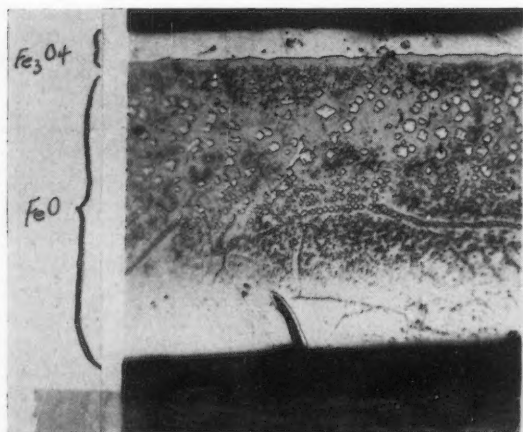
Figure 3—Oxide scale on Armco iron after five minutes in pure oxygen. This is an adherent oxide. X260. Etchant 20 percent HCl.

Figure 4—Oxide scale on Armco iron after five minutes at 2000 degrees F (1090 degrees C). Opposite side of same specimen as in Figure 3. This is a separated oxide. X260. Etchant 20 percent HCl.

Fe_3O_4 in Figure 2. The measurements were taken directly from photomicrographs.

The thicknesses plotted above are in each case from measurements taken on an adherent scale. It is important to note that in every case only about one half of the surface was covered with an adherent oxide. The oxide on the remaining surface had separated from the metal, and occurred in a great variety of relative thicknesses. No constant relationship among the oxide layers occurred on the separated oxide. Figures 3 to 6 show examples of such behavior. In Figures 3 and 5 the Fe_2O_3 layer is not resolved, but there is a thin one present. The precipitation in the FeO phase is Fe_3O_4 formed by cooling

below about 1060 degrees F (570 degrees C). It will be discussed in detail later. The iron undergoes more contraction on cooling than the oxide, so only rarely is any part of the oxide on flat specimens still adherent after cooling. That part which was adherent at temperature may be identified by the smaller amounts of Fe_3O_4 that precipitate and the concentration gradient of the precipitate. Figure 5 illustrates well the adherent type while Figure 6 shows the indications of separation of metal and oxide. Figures 8 through 12 further illustrate different structures all occurring on the same specimen. Figure 7 is a key to Figures 8 through 12. A more quantitative means of determining separation is by measuring FeO/Fe_3O_4 thickness ratios over the entire surface. It will be found that this ratio varies up to a maximum. The maximum represents the lowest state of oxidation of the film and, therefore, the portion which was in contact with the metal. Figure 12 shows a transition between adherent and separated oxide. Almost without exception, the oxide on one complete side of a specimen was adherent, while the opposite side was separated. Cooling cracks may be observed, but it is easy to distinguish a cooling crack and a separation at temperature. The latter is always accompanied by transformation to a higher oxide.

It becomes increasingly apparent that studies of adherent oxide represent only a portion of the total oxidation process. Complementary experiments on iron wires show similar results. An adherent oxide forms on one side with a thinner more highly oxidized layer on the opposite side as shown by Figure 13. Figure 14 is a schematic diagram of the oxidation process on a small iron wire.

It is apparent that for thin sheets and wires there is a controlling influence of one side of the piece upon the opposite side.

It appears reasonably certain that for the adherent oxide the Fe/FeO interface remains practically fixed in space. If the FeO reaction occurs solely by dif-
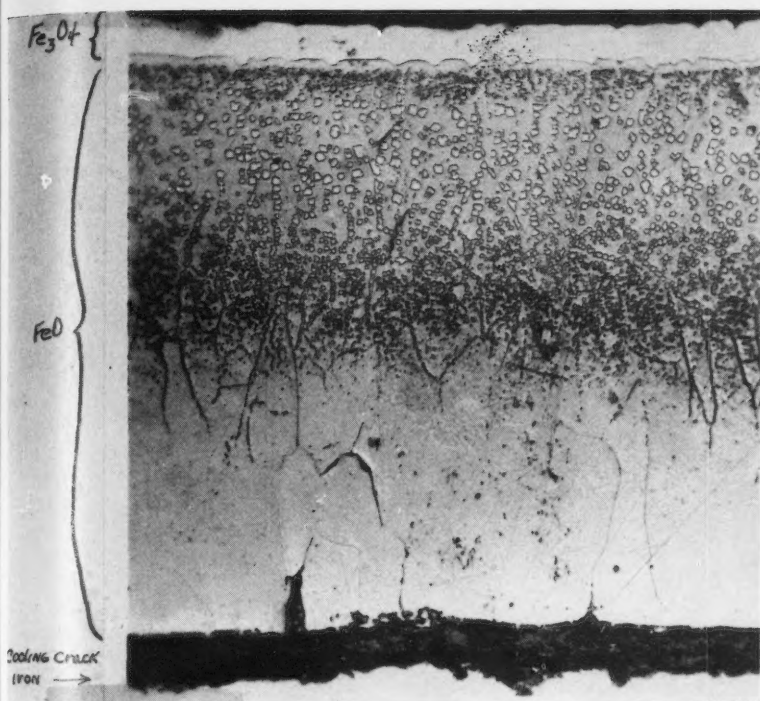
Figure 5—Oxide scale on Armco iron after 40 minutes at 1800 dergees F (980 degrees C). This is an adherent oxide. X260. Etchant 20 percent HCl.

fusion of iron there should be no movement. Consider the implications of such a reaction if the entire surface were covered with an adherent oxide. As more and more iron diffuses out into the oxide, voids and vacancies must develop somewhere within the bounds of the inner oxide boundary. Formation of microvoids in the metal is ruled out on both theoretical and experimental grounds. Visual examination of the polished cross-sections shows that the required void always forms by separation of the metal from the oxide over a certain area. Once this void has formed, further oxidation results in continued growth of the adherent layer, and further separation of the non-adherent layer. The remaining iron stays in contact with the adherent layer which means that as the iron is consumed it retreats further from the separated layer. Periodic cracking of the separated layer permits oxygen to enter and

Figure 6—Oxide scale on Armco iron after 40 minutes at 1800 degrees F (980 degrees C). Opposite side of same specimen as in Figure 5. This is a separated oxide. X260. Etchant 20 percent HCl.

– – – – Original Metal Cross Section
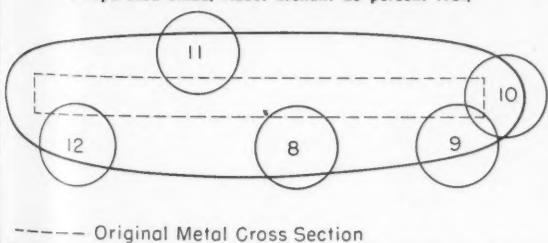
Figure 7—Diagram of cross section from which Figures 8, 9, 10, 11 and 12 were taken. Key indicates position of each.
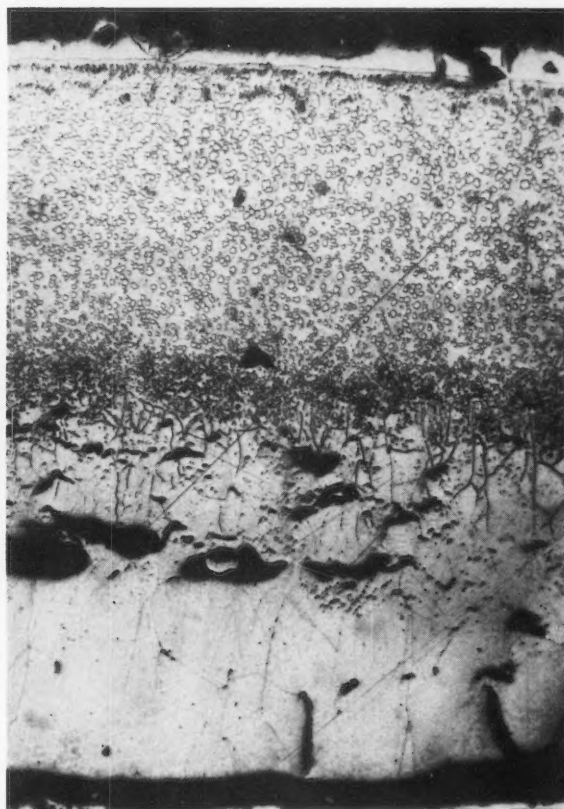
Figure 8—Oxide scale on Armco iron after two hours and five minutes at 2000 degrees F (1090 degrees C) in pure oxygen. See Figure 7 for key to position on specimen. This is an adherent oxide. X120. Etchant 20 percent HCl.

Figure 9—Oxide scale on Armco iron after two hours and five minutes at 2000 degrees F (1090 degrees C) in pure oxygen. Changing from adherent to separated oxide. See Figure 7 for key to position on specimen. X120. Etchant 20 percent HCl.

Figure 10—Oxide scale on Armco iron after two hours and five minutes at 2000 degrees F (1090 degrees C) in pure oxygen. This is a separated oxide. See Figure 7 for key to position on specimen. X120. Etchant 20 percent HCl.

form a thin oxide on the retreating iron surface. Each time this happens the newly formed oxide again separates and the process continues. The resultant structure is a number of layers of oxide all tending toward Fe_2O_3. Figure 11 is an excellent example of this. The oxide has transformed almost entirely to Fe_2O_3.

Specimens were run at 200 degrees F (110 degrees C) intervals from 1200 degrees F (650 degrees C) to 2200 degrees F (1205 degrees C) and the same type of structure was noted at each temperature. Internal voids always formed. Simply breaking in two a completely oxidized specimen may be misleading for the structure shown in Figure 11 may appear to be a continuous phase. If it has been steadily and frequently cracking as it does with increasing temperature, then it will keep close to the retreating iron and as the final bit of iron is consumed there will be only a tiny separation between the adherent and separated oxides. Careful metallographic examination is necessary to distinguish the actual structure.

Additional experiments on ½-inch diameter specimens supported Pfeil's original statement that on this size of specimen no continuous adherent oxide is formed. It is believed that the two types of behavior are not fundamentally different. It is apparent on the thin specimens that the reaction on one face influences the reaction on the opposite face. If the faces are separated by a greater distance, as in a specimen of large cross-section, then less interaction would be expected. On increasing the specimen thickness further, a critical distance is reached over which the required interaction force cannot operate. Yet it was just stated that the formation of voids indicates the necessity of one reaction for the existence of the other. The explanation for a large specimen is that the two phenomena occur side by side on the same surface. On a small piece the two reaction sites retain their identity, but on a large piece they are constantly interchanging roles. The result for the larger piece is the observed broken mass of oxide particles resting on a retreating metal surface.

The most likely explanation of this two-fold nature of oxidation is based on diffusion of lattice vacancies in the iron. Solution of an iron atom in the oxide lattice produces a vacancy in the iron lattice. As the concentration of vacancies increases, they diffuse back to the surface under the separated oxide. Arrival of such a vacancy at a free surface results in its dissipation. Such a process is equivalent to a steady supply of iron at the reaction interface through a self-diffusion process. Fick's laws of diffusion will hold in the present case, for they depend upon no mechanistic assumption. In order to apply Fick's first law,

$$\frac{dm}{dt} = D_{vacancy} \frac{dc}{dx} \tag{1}$$

(where dm is amount of material transported in the interval dt, $D_{vacancy}$ is the vacancy diffusion constant, and dc/dx is the concentration gradient.) It is necessary to use the same units for m and c. The term m may be calculated directly in terms of numbers of iron atoms from the oxidation rate equation. The term c could also be expressed in terms of iron concentration, for an excess of lattice vacancies at any point means a lower concentration of iron. However, it is more convenient to express the concentration in terms of lattice defects. The iron may be expressed in the same manner, for one iron atom moving in a given direction is equivalent to a vacancy moving in the opposite direction. Whatever the actual method of movement it may be formally expressed in terms of a gradient of vacant lattice sites, since these are being produced on one side and removed on the other.

Any crystal has an equilibrium number of lattice vacancies at any temperature. The actual number depends not only upon the temperature but upon the energy required to form a vacancy,[12] thus

$$\frac{n}{N} = e^{-E/RT} \tag{2}$$

where n = number of lattice vacancies
   N = total number of lattice sites
   e = base of natural logs
   E = energy required to form a vacant lattice site
   R = gas constant
   T = absolute temperature.

The case of oxidation is different from ordinary self diffusion in that there is a vacancy concentration gradient present resulting from the generation of vacancies at the Fe-FeO interface. It is not possible to calculate with accuracy the permissible concentration to which the vacancies may rise at the Fe/FeO interface. In order to do so it would be necessary to know the energy required to form a vacancy as a function of the number of vacancies already present. A schematic diagram of the vacancy concentration gradient during oxidation is in Figure 15.

Since the maximum concentra-
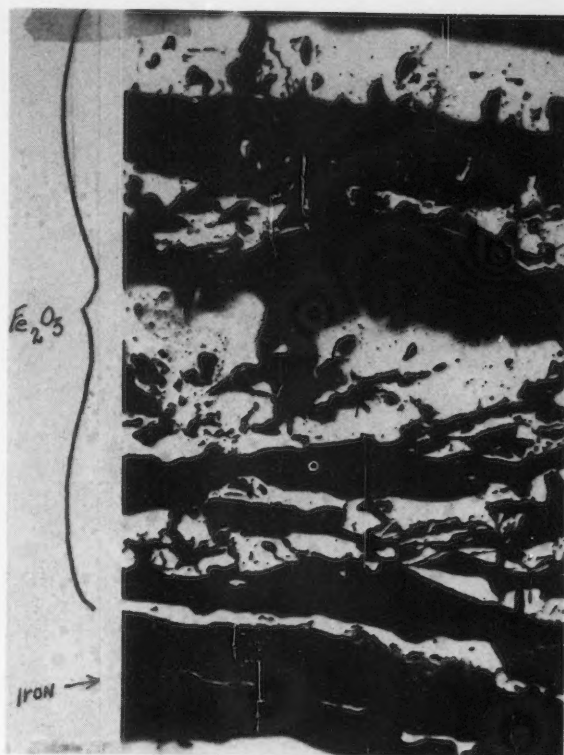
Figure 11—Oxide scale on Armco iron after two hours and five minutes at 2000 degrees F (1090 degrees C) in pure oxygen. This is a separated oxide. See Figure 7 for key to position on specimen. X120. Etchant 20 percent HCl.
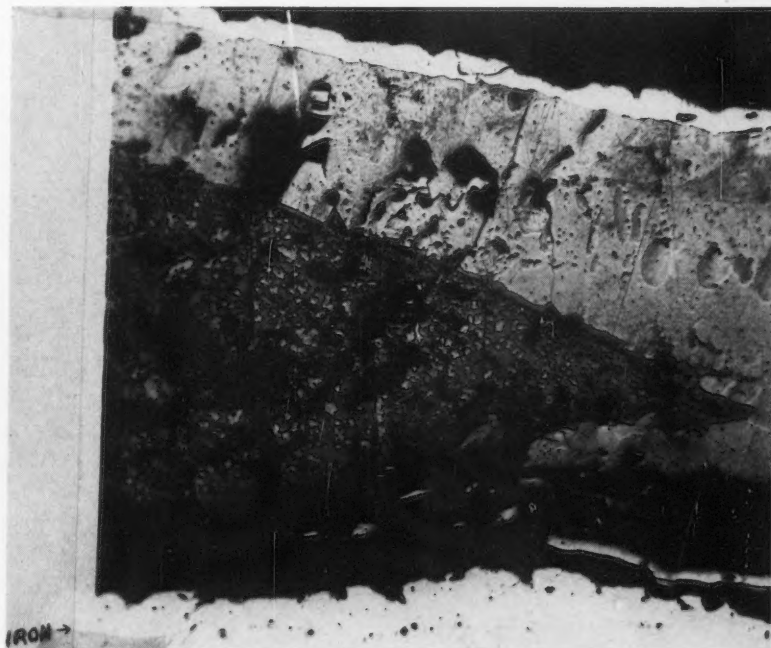
Figure 12—Oxide scale on Armco iron after two hours and five minutes at 2000 degrees F (1090 degrees C). Transition from separated to adherent oxide. See Figure 7 for key to position on specimen. X120. Etchant 20 percent HCl. FeO to the left, Fe₃O₄ to the right, Fe bottom.
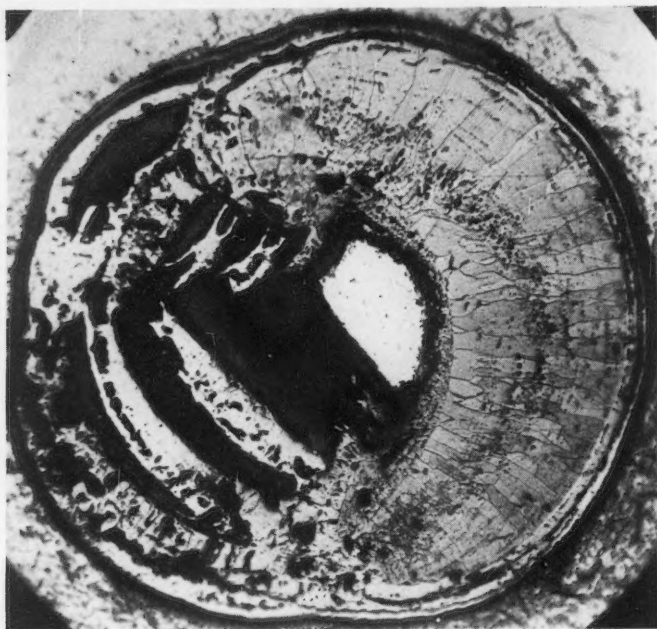
Figure 13—Oxide scale on iron wire after 14 hours at 1500 degrees F (805 degrees C) in pure oxygen. X 85. Etchant 20 percent HCl.

Iron

Iron Oxide
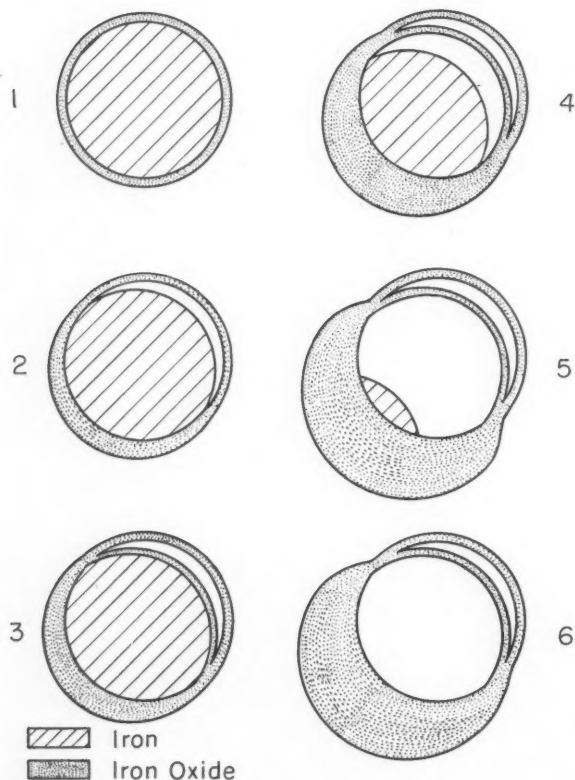
Oxidation of a Small Iron Wire

Figure 14—Schematic diagram of oxidation of a small iron wire.

tion of vacancies is not known then dc also is not known exactly. The term dx is found experimentally by measuring the actual thickness of iron which is oxidizing with an adherent film on one side and a bare surface on the other, and assuming a linear gradient.

The quantity dm/dt varies as the requirement of the oxidation reaction. If the oxidation is diffusion controlled, then

$$dm/dt = K/m \qquad (3$$

where K is the rate constant and m is the amount of metal already in the oxide. Combining this with Equation (2,

$$D_{vacancy} \ dc/dx = K/m \qquad (4$$

The supply of metal to the oxide will be greatest in the early part of oxidation. Careful study of a number of specimens indicates that the oxide may freely grow to some critical thickness before it is necessary to dispose of the excess vacancies stored up in the metal. It is at this point that the type of oxide to form on the metal is decided. A portion of oxide separates and provides a sump for vacancies. The edges of such a separation would be under high stress because of compressive stresses that are intensified by the sharp edges acting as stress raisers. It would tend, therefore, to crack away from the metal over the entire side it started on. If the thickness of the piece is small enough, that is, equal to or less than the maximum permissible dx, then an adherent layer can form on the side opposite the separation. If the thickness of the piece is greater than this critical value then the Pfeil type layer will form because the gradient to the opposite side would be too shallow to nourish the oxidation reaction. The amount of metal supplied to the oxide decreases steadily, and the specimen thickness decreases as oxidation continues. If an adherent film starts at this time, it will remain until the iron is consumed.

The above statements may be conveniently summarized as follows:

1) For an adherent film;
$$dm_{ox}/dt = D_{vacancy} \ dc/dx_{thickness} \qquad (5$$

2) For a Pfeil type film;
$$dm_{ox}/dt > D_{vacancy} \ dc/dx_{thickness} \qquad (6$$

From previous work on diffusion of vacancies[12] it is known that
$$D_{vacancy} = D_{\alpha} \cdot N/n \qquad (7$$

where D_{α} is the self diffusion constant of gamma iron. The ratio n/N may be evaluated from Equation (2 by knowing E, the energy per mol of vacancies. This will be taken as one half of the value found by subtracting the heat of fusion and RT from the heat of vaporization,[13] that is

$$E = \frac{1}{2} (\Delta H_{vap} - \Delta H_{fus} - RT) \qquad (8$$

From the thermodynamic values of gamma iron,[14] E is calculated to be 43.2 kilocalories per gram mole at 2000 degrees F (1090 degrees C). The value of n/N is found to be 1.43 x 10^{-7}. According to Birchenall and Mehl,[15]

$$D_\alpha = 5.8e^{-74200/RT} \qquad (9$$

At 2000 degree F (1090 degrees C) D_α is 9.7 x 10^{-12}. Substituting these values in Equation (7, $D_{vacancy}$ is found to be 7.0 x 10^{-5}. Fick's first law as expressed in Equation (5 may now be solved for dc by direct substitution. The ratio dm_{ox}/dt is taken as the instantaneous rate of oxidation, found from the analytical expression of the oxidation rate data. The thickness dx is taken as the original specimen thickness less the thickness of metal consumed in oxidation. Since a linear gradient is assumed the differentials dc and dx amy be replaced by increments.

$$\Delta c = c_{max} - c_{equil} = \frac{\Delta x}{D_{vacancy}} \cdot dm_{ox}/dt \qquad (10$$

where c_{max} = maximum concentration of vacancies and c_{equil} = equilibrium concentration of vacancies.

The value of c_{equil} may be calculated from the fact that n/N is equal to the ratio of concentrations of vacancies and lattice sites. Concentration of lattice sites may be taken as approximately the concentration of atoms, which is known from density values. c_{equil} is, therefore, 1.2 x 10^{16} vacancies per cc. Equation (10 may be solved at any time t. On evaluating c_{max} at five minutes after zero time, it is found to be 3.7 x 10^{21} and n/N at the same point is 4.1 x 10^{-2}, or about four out of every hundred lattice sites at the Fe/FeO interface are vacant. This means that in order for iron to be supplied at the Fe/FeO interface by self-diffusion of holes to the opposite side of the specimen, it is necessary to have about 2 x 10^{5} more vacancies at the Fe/FeO interface than at equilibrium.

Figure 16 is a plot of vacancy concentration against time, for various thicknesses of specimen. The family of curves at the top of this figure shows, at any time and specimen thickness, the concentration of vacancies that would be required at the Fe/FeO interface if an adherent film is growing on one side with a non-adherent film on the opposite side. The family of curves at the bottom of the figure shows the concentration of vacancies that would be in the metal if no separation has occurred calculated from the total number of iron atoms that have moved into the oxide, divided by the remaining volume of metal. Each iron atom that enters the oxide is assumed to leave a vacancy in the metal. Also,

before the oxide separates from the metal, the vacancies are assumed to be uniformly distributed through the metal. The calculations are on the basis of an infinite sheet. Since c_{max} is defined as the concentration of vacancies required at the Fe/FeO interface to make the new mechanism work, a separation does not start the new mechanism working unless the uniform distribution of vacancies has reached c_{max}. The series of intersections of the two families of curves on Figure 16 show that for thicker specimens a longer time is required to permit the intersection of the two curves. For all thicknesses at this temperature (2000 degrees F, 1090 degrees C) the intersection occurs at a n/N value of 4.1 x 10^{-2}. It is likely that thicker oxide
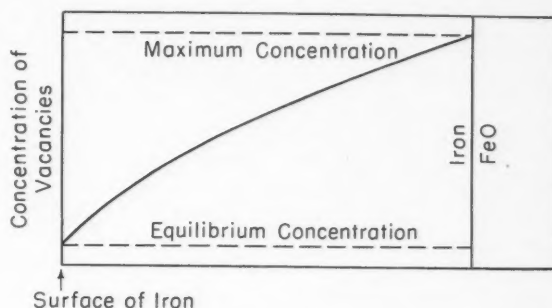
Figure 15—Schematic diagram of the proposed concentration distribution of vacancies during high temperature oxidation.
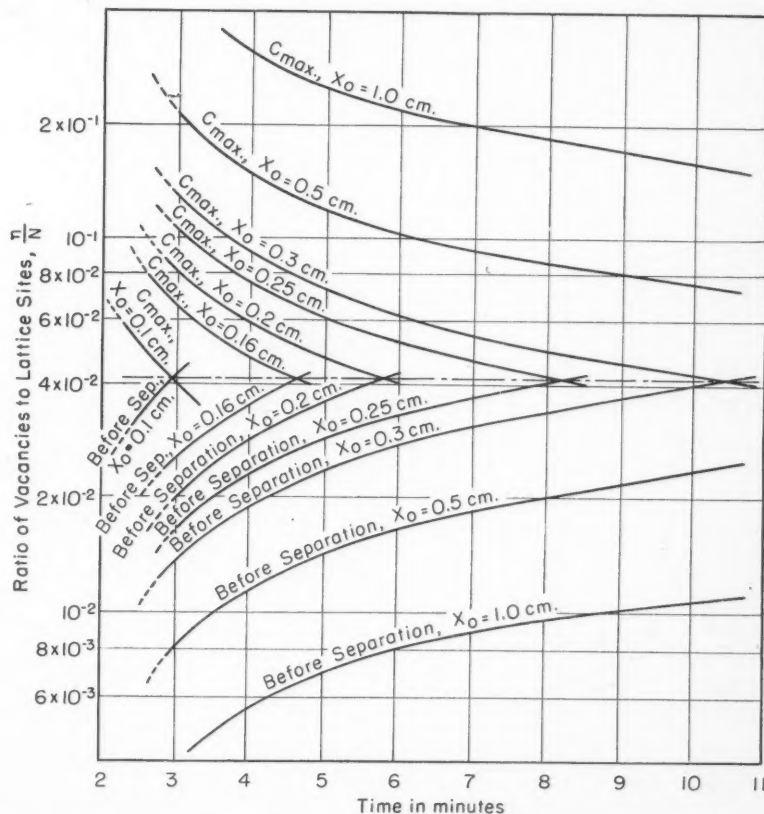
Figure 16—Plot of Vacancy Concentrations vs Time for various specimen thicknesses. The upper curves show c_{max}. The lower curves show vacancy concentration before the oxide separated from the metal. The term x_o means thickness of specimen at the start of oxidation.
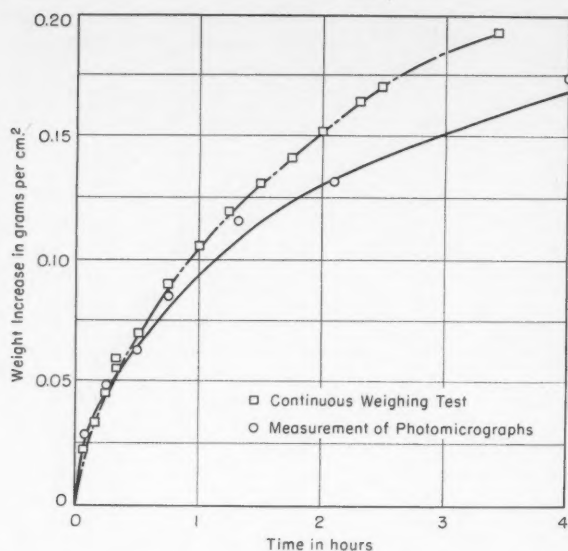
Figure 17—Increase in weight per square cm of iron surface during oxidation in pure oxygen at 2000 degrees F (1090 degrees C). Comparison of weight change method with microscopic method.

Figure 19—Fe_3O_4 precipitate in FeO. Oxide formed on specimen of Armco iron oxidized in pure oxygen at 2000 degrees F (1090 degrees C) for two hours and five minutes. Dark areas are FeO and light areas are Fe_3O_4. X1300. Etchant 20 percent HCl.

Figure 18—Fe_3O_4 precipitate in FeO. Oxide formed on specimen of Armco iron oxidized in pure oxygen at 2000 degrees F (1090 degrees C) for two hours and five minutes. X1300. Etchant 20 percent HCl.

Figure 20—Fe_2O_3 precipitate in Fe_3O_4. Oxide formed on Armco iron in pure oxygen at 2200 degrees F (1205 degrees C) for one hour and 20 minutes. X155. Etchant 20 percent HCl.

films encourage separation because of internal stresses. Thick specimens will, therefore, be expected to start separating before the vacancy concentration is high enough to permit an adherent film. In this case a Pfeil type layer forms. The critical thickness of specimen cannot be calculated because it depends upon unknown stresses in the oxide.

Weight vs. Time Measurements

The photomicrographs in the previous section clearly demonstrate that various areas of the specimen surface oxidize in radically different manners. Many kinetic studies of oxidation have been made

by using the continuous weight technique. The latter is, of course, an averaging device which does not separate different reactions that may be occurring. It is, therefore, interesting to compare the rate measured on adherent films with the rate found by continuous weighing. Figure 17 shows such a comparison for iron sheets of the thickness used in these experiments (0.16 cm). The information from the microscopic work is plotted by calculating the weight of oxygen required to make the measured volume of oxide. Oxide density must be used in these calcula-

tions and this means that each separate oxide layer is assumed to be of constant composition. An error is introduced but it is not large and it is unavoidable. Only the sum of the FeO and Fe_3O_4 layers is plotted.

Surprisingly, the two methods agree within experimental error for about the first hour. Because of its random nature, the oxidation of the side of the specimen on which the oxide separates cannot accurately be expressed analytically. The closest approach would probably be a linear rate. Therefore, part of the specimen is oxidizing according to .the parabolic law and part in a pseudolinear fashion. It is unexpected that an average of the two should be practically identical with the first over a considerable length of time. This coincidence is not taken as proof that the same agreement will be found at other specimen thicknesses. The agreement does not mean that oxide separation phenomena occurs only after the first hour. It is readily observable after five minutes.

Precipitation on Cooling FeO and Fe₃O₄

It is well known that FeO is unstable below about 1060 degrees F (570 degrees C). On slow cooling below this temperature it transforms to $Fe + Fe_3O_4$. Most of the previous photographs have illustrated the manner of formation of the precipitate. Notice particularly in Figure 5 that there is a marked gradient across the FeO layer, demonstrating the variation in composition of the FeO. The precipitate forms most readily along grain boundaries. Figure 18 is a higher magnification detail of the Fe_3O_4 precipitated at FeO grain boundaries. There are small dark areas of precipitate close to the Fe_3O_4 in the FeO. These are not resolved in the photographs preceding Figure 18 and

there is some doubt concerning their identity.

Figure 19 shows that they are also Fe_3O_4 particles. Figure 19 is taken on the sharp point of FeO that penetrates into the Fe_3O_4 field in Figure 12. Transformation of FeO → Fe_3O_4 evidently does not proceed
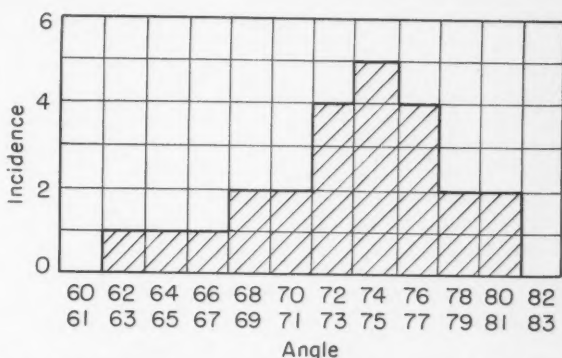
Figure 21—Plot of Incidence vs Angle of Intersection for Fe_2O_3 precipitate formed on cooling Fe_3O_4. Oxide formed on Armco iron in pure oxygen at 2200 degrees F (1205 degrees C) for various times.
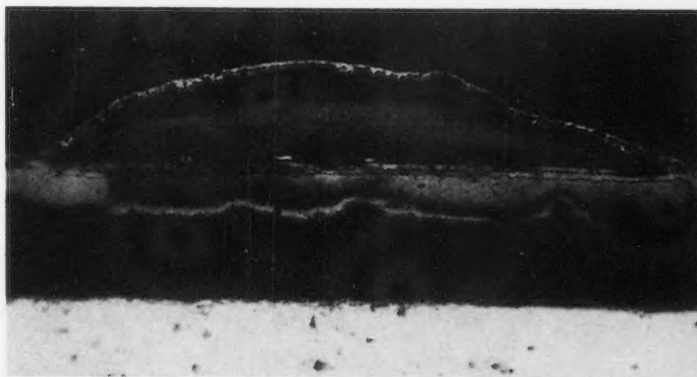
Figure 22—Oxide and blister formed on Armco iron oxidized in dry air at 1200 degrees F (650 degrees C) for 20 minutes. X130. Etchant 20 percent HCl.
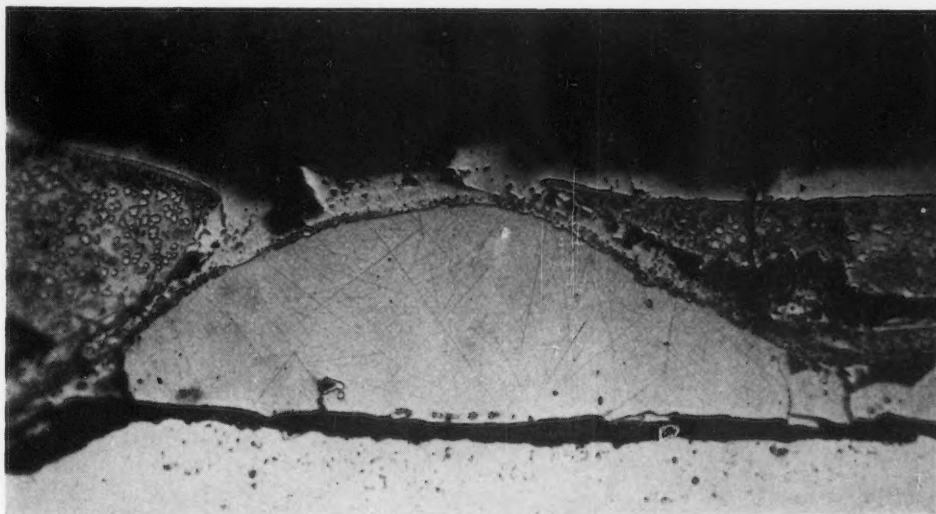
Figure 23—Blister and oxide formed on Armco iron heated in dry air to 2200 degrees F (1205 degrees C) for five minutes. X155. Etchant 20 percent HCl.

along a straight front when the reaction takes place in the oxide not in contact with the iron.

A precipitate of a different sort has been observed in slowly cooled magnetite (Fe_3O_4). Figure 20 shows a lamellar precipitate occurring along several directions in a single grain. Magnetite may exist at high temperatures with an oxygen rich composition. On cooling such a composition it moves into the $Fe_2O_3 +$ Fe_3O_4 field as the composition limits of the magnetite becomes more restricted. The precipitate in the photograph is identified as hematite (Fe_2O_3) by etch characteristics and hardness (see later section) and by the important fact that it is frequently continuous with the overlying Fe_2O_3 layer.

The crystal planes on which the precipitate forms are of interest.. They may be identified by the angle measuring technique described by C. S. Smith[16] for determining true angle of intersection of grain boundaries. When incidence is plotted against angle of intersection there is a maximum at the true normal angle. Figure 21 is such a plot for this precipitate. The maximum frequency of occurrence is close to 73°. Magnetite may be considered as a slightly distorted close packed cubic structure of oxygen ions[17] with metal ions in certain interstices. The [111] planes in cubic crystals intersect at an angle of 70°32'. This close agreement fits with the previously known information[18] that the [111] plane of magnetite forms parallel to the [0001] plane in hematite. Thus, hematite precipitating in magnetite would be expected to form on [111] magnetite planes and it is found to do so.
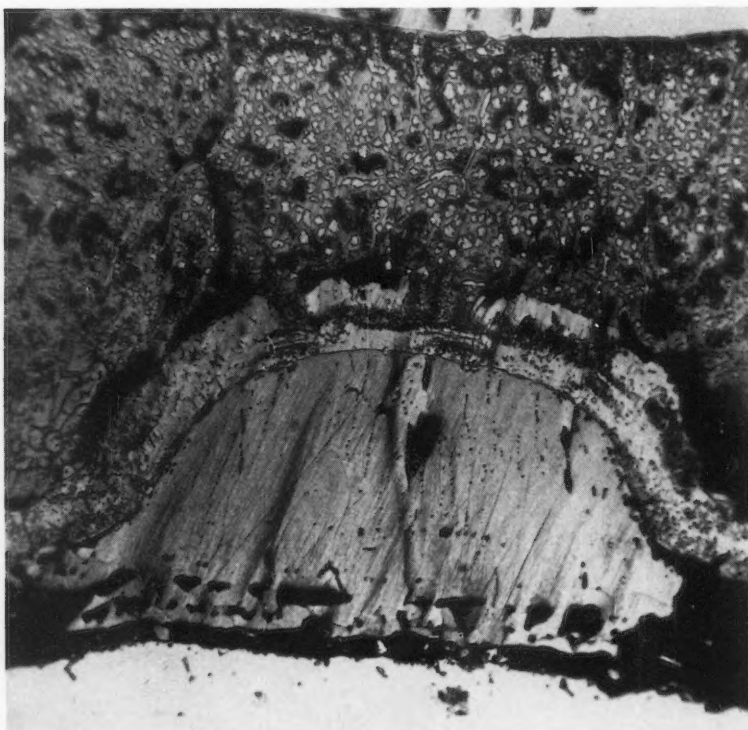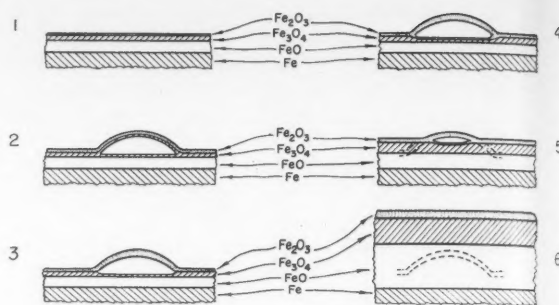
History of Blister on Iron Oxide Scale

Figure 25—Schematic drawing of growth of oxide blister on iron.

Blisters on Iron Oxide

Blisters are observed on iron oxide under various conditions. Those studied here were formed by heating specimens directly in dry air to the temperature of oxidation. This is different from the previous experiments in that they involved heating the specimen in argon. If a specimen is watched after being put into the furnace it is possible to see blisters actually form as the specimen is approaching the furnace temperature. Figure 22 is a cross section of a blister removed from the furnace shortly after the specimen reached temperature. The blister is seen to be superficial, with the bulk of the film undisturbed.

After a longer period, depending upon temperature, the surface of the oxide appears perfectly smooth and cross sections indicate no evidence of blisters. In order to trace the blisters to this stage, a thin coating of chromium oxide was put on the surface to serve as a marker. Figures 23 and 24 show such specimens with blisters in later stages of growth. The chromium oxide marks the blister not only by delineating it with a separate phase, but by controlling the composition within the blister so that no precipitation occurs on cooling. The information from these and other photographs is summarized schematically in Figure 25. The drawings show that the break forms in the Fe_3O_4 layer. Once the blister forms it does not change in size or position, but the main oxide body continues growing so that the blister eventually is buried deep in the FeO layer. Formation of the blister apparently has little effect on the rate of growth of the oxide under it. It is not suggested that all blisters that form are of this type. Very probably a different atmosphere or a different heating cycle will produce blistering of the total oxide thickness.

Qualitative Indication of Oxygen Diffusion

The chromium oxide coating put

Figure 24—Oxide and blister formed on Armco iron heated in dry air to 2000 degrees F (1090 degrees C) for three hours. X120. Etchant, 20 percent HCl.

on the surface of the metal will serve as a diffusion marker over the areas that did not blister. Measurements on oxides grown at 2000 degrees F (1090 degrees C) show that the chromium oxide moves away from the metal 1/10 of the thickness of the FeO layer. A rough estimate is that the diffusivity of the oxygen in FeO is 1/10 the diffusivity of the iron. Accurate measurements are not justified because the presence of chromium ion will undoubtedly modify the character of the oxide.

Microhardness Measurements on Oxides

The various oxide phases are easily identified by etching characteristics. In addition, it was found that each had a different hardness as measured by a diamond indentor on a Bergsman microhardness device. Data from this source are not directly comparable with normal hardness readings. They are of use only in comparison with one another. Representative averages for each of the three oxides are:

Phase	Hardness Number
FeO	50
Fe_3O_4	60
Fe_2O_3	90

Small amounts of precipitate may be identified by these hardness characteristics.

Summary and Conclusions

1. Diffusion of lattice vacancies in the metal is shown to influence the type of oxide formed on iron at high temperatures.

2. Specimen thickness has an influence on the type of scale formed on the surface. An adherent layer forms on one side of thin specimens, and on the opposite side a loose, more highly oxidized layer forms. The oxide layer on a large specimen is uniform over the entire surface but of a different character from the layers formed on a thin specimen.

3. Measurements on photomicrographs of adherent oxide formed at 2000 degrees F (1090 degrees C) give the same rate law as continuous weighing experiments during the first hour of oxidation.

4. Blisters formed by heating iron are shown to be covered by the oxide subsequently formed.

5. Precipitates for Fe_3O_4 in FeO and of Fe_2O_3 in Fe_3O_4 are described. Fe_2O_3 is shown to precipitate on [111] planes in Fe_3O_4.

6. The three iron oxide phases may be distinguished by microhardness measurements.

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Corrosion by Some Organic Acids And Related Compounds*

By H. O. TEEPLE*

IN VIEW of the current wide use of organic compounds, particularly those of the aliphatic series, the lower carbon compounds, it was thought that a summary of the behavior of various metals and alloys in these compounds would be of interest.

A review of the literature covering corrosion by such organic compounds indicates that some information is available, part of it being specific, part being general and part being rather casual. Because of possible interest a brief annotated bibliography is appended.

This paper is concerned with a discussion of the behavior of various metals and alloys in contact with acids such as formic, acetic and their mixtures, butyric acid, anhydrides, corresponding aldehydes, ketones, alcohols and esters. The discussion is presented in part form as is indicated by the subject matter covered. The behavior of the materials of construction is illustrated by appropriate plant and laboratory corrosion data.

I—Acids

The first part of the article, that concerning the behavior of metals and alloys in some organic acids, is broken down into a discussion of (A) the essentially pure acids, (B) mixtures of the acids with other compounds and (C) various anhydrides.

A. *Formic Acid*

In general, formic acid behaves much like acetic acid, to be discussed presently, but with some marked exceptions. For example, aluminum is corroded at a fairly rapid rate by formic acid even at room temperature.[1]

The copper base alloys, that is brasses, silicon bronzes, aluminum bronzes and phosphor bronzes generally are corroded at rates too high to permit their use in comparison with other materials of construction. If, however, acid concentrations or temperatures are low, these alloys show a useful service life.

The austenitic stainless steels, as a group, appear to provide more resistance to corrosion by formic acid than other commonly used materials of construction. An exception seems to be the 18-8 steels in hot vapors.

In the manufacture of formic acid some field cor-

Abstract

In this paper there are discussed the results of corrosion tests in various organic acids, principally those of the lower aliphatic series. Aqueous solutions of the acids and mixtures are considered. Related Compounds, such as aldehydes, ketones, esters and anhydrides are also discussed.

The corrosive conditions studied are those which prevailed during the production or use of these compounds. Where appropriate, laboratory test results are included.

The materials of construction discussed are the ferrous and non-ferrous alloys. These include the stainless steels, the special autenitic stainless steels, copper and copper-base alloys, nickel and nickel-base alloys.

rosion tests were made which are summarized in Table I.

TABLE I
Field Test for 100 Days in 90% Formic Acid

MATERIAL:	INDICATED CORROSION RATE—IPY			
	In Still—212° F.		In Storage—Atm. Temp.	
	Liquid	Vapor	Liquid	Vapor
Type 316 S. S.	<0.001	0.002	<0.001	<0.001
Type 304 S. S.	<0.001	0.026	<0.001	<0.001
Nickel	0.018	0.007	0.004	0.007
Inconel	0.02	0.013	0.004	0.006
Copper	0.038	0.006	0.013	0.012
Silicon Bronze	0.035	0.009	0.009	0.009
Monel	0.013	0.005	0.010	0.021
Aluminum 2S	0.27	0.10	0.038	1.0

Other data on Monel in formic acid which illustrate the effect of temperature are given in Table II.

TABLE II
Laboratory Test of 11 Days Duration in 30% Formic Acid

MATERIAL:	Indicated Corrosion Rate, Ipy	
	Room Temp.	130-150° F
Monel	0.003	0.023

A similar temperature effect is noted in the case of aluminum bronze and is shown in Table III.

TABLE III
Laboratory Test in 35% Formic Acid

MATERIAL:	Indicated Corrosion Rate, Ipy	
	28 Days at 72° F	35 Days at 192° F
Al. Bronze (10% Al, 3.5% Fe)	0.003	0.019

In addition to temperature, the performance of the copper base alloys, Monel and nickel would be expected to be influenced materially by the degree of aeration, i.e. air saturated acid solutions being the more corrosive.

In the case of the Hastelloy Alloys B and C, the effect of formic acid is indicated by the data shown in Table IV.

TABLE IV[2]

Laboratory Test in Aerated Formic Acid of Various Concentrations at 158° F

ALLOY:	Indicated Corrosion Rates, Ipy				
	Acid Concentration				
	10%	20%	40%	60%	85%
Hastelloy B.............	0.048	0.031	0.031	0.025	0.006
Hastelloy C.............	<0.001	0.001	0.002	0.001	0.001

Departures from the general behavior indicated above appear to occur at higher temperatures even when the formic acid concentration is low. This point is based upon the data shown in Table V.

TABLE V

Field Corrosion Test for 27 Days in a 2% Formic Acid, 1.5% Formaldehyde Solution at 300° F

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel...........................	0.0003
Nickel..........................	0.0004
Copper.........................	0.0008
Silicon Bronze.................	0.0008
70/30 Cu Ni....................	0.0008
Sb. Admiralty..................	0.0008
10 percent Al. Bronze.........	0.0010
Type 317 S. S.................	0.0024
Inconel........................	0.0031
Type 316 S. S.................	0.0040
Type 304 S. S.................	0.018
Type 347 S. S.................	0.018
Mild Steel.....................	>0.5

These data show low corrosion rates for copper and the copper base alloys as well as Monel and nickel. The 18-8 stainless steels do not appear to be adequately resistant although the molybdenum bearing austenitic stainless steels show much better resistance than the 18-8 steels. The advantage of Type 317 over Type 316, it might be remarked, is not necessarily due to the higher molybdenum content, but probably due to the higher alloy content of which chromium undoubtedly plays an important part.

B. *Acetic Acid*

Acetic acid is by far the most commercially important organic of the lower carbon acids in the aliphatic series. A considerable amount of work has been done relating to the corrosive effect of this acid.

The discussion to be presented in the case of acetic acid is rather extensive and to clarify the presentation, first consideration will be the effects of concentration, temperature and other factors on the corrosion of metals and alloys by acetic acid alone, and following this the effects of various impurities in the acid will be considered.

With reference to acetic acid alone, there are available a rather large number of metals and alloys

offering reasonable degrees of resistance to corrosion by acetic acid.

Copper and copper base alloys have been used extensively in the past for handling acetic acid.

These materials are fairly satisfactory over rather wide concentration levels and temperature. However, certain factors or a combination of factors, such as aeration, concentration, temperature and velocity may seriously affect the suitability of these materials in acetic acid service. For critical applications other alloys possessing more tolerance to these factors are generally preferred.

An illustration showing the effects of aeration is provided by the data in Table VI.

TABLE VI[3]

Laboratory Test in 6% Acetic Acid at 86° F Duration of Test—96 Hours

MATERIAL:	Indicated Corrosion Rate, Ipy	
	Non-Aerated	Aerated
Copper........................	0.003	0.017
70/30 Cu Ni...................	0.003	0.012

The effect of concentration and temperature is illustrated by the data appearing in Tables VII through IX.

TABLE VII[4]

Laboratory Tests of Phosphor Bronze in Acetic Acid of Different Concentrations and Temperatures

Concentration	Indicated Corrosion Rates, Ipy		
	70° F	122° F	Boiling
10 Percent....................	0.003	0.009	0.080
50 Percent....................	0.005	0.022	0.036
75 Percent....................	0.008	0.025	0.040
Glacial.......................	0.026	0.038	1.4

TABLE VIII

Laboratory Tests of 10% Aluminum Bronze* in Acetic Acid of Different Concentrations and Temperatures

Concentration:	Indicated Corrosion Rate, Ipy	
	72° F	192° F
10 Percent....................	0.002	....
35 Percent....................	0.003	0.020
50 Percent....................	0.004	....

* Contains 3.5 percent Fe.

TABLE IX

Laboratory Tests of 15 Days Duration in Acetic Acid of Different Concentrations and Temperatures

MATERIAL:	Indicated Corrosion Rates, Ipy		
	27°-70° F	Boiling Glacial Liquid	Boiling Glacial Vapors
88-10-2 Bronze................	0.0001	0.62	0.012
85-5-5-5 Bronze...............	0.0005	0.68	0.17
7 Percent Al. Bronze..........	0.0007	0.10	0.009
10 Percent Al. Bronze.........	0.0002	0.003	0.009
10 Percent Al., 3.5 Percent Fe Bronze	0.0008	0.002	0.005

It is interesting to note that a plant corrosion test of 11 days duration in 99 percent boiling acetic acid showed a corrosion rate of 0.006 ipy for copper, 0.002 ipy for a 9 percent aluminum bronze. Another plant corrosion test of 157 days duration in a 98 percent

acetic acid, 2 percent water solution at 86 degrees F showed a corrosion rate of 0.008 ipy for copper and 0.003 ipy for a silicon bronze. A field corrosion test of 115 days duration made in a storage tank holding 24 percent acetic acid at 95 degrees F showed a corrosion rate of 0.002 ipy for both copper and silicon bronze. Another plant test of 82 days duration in a glacial acetic acid condenser, i.e., vapors at 212 degrees-248 degrees F showed a corrosion rate of 0.067 ipy for copper.

In summary, while copper has appreciable resistance to corrosion by acetic acid solutions, the aluminum bronzes and the silicon bronzes appear to offer greater corrosion resistance, particularly at higher concentrations at higher temperatures.

Aluminum shows varying resistance to corrosion by acetic acid, though generally satisfactory by all concentrations up to 99 percent at temperatures up to about 150 degrees F. Aluminum is, however, readily attacked by 100 percent acid at room temperature. The addition or the presence of a small quantity of water, usually about one-half of one percent, will permit the use of aluminum resulting in a satisfactory service life.

The effect of concentration at the boiling point is shown by the data in Table X.

TABLE X[5]
Laboratory Test of Aluminum 2S in Various Concentrations of Boiling Acetic Acid Solutions

Acid Concentration, Percent	Indicated Corrosion Rate, Ipy
5	0.48
10	0.42
19	0.42
33	0.41
48	0.36
57	0.31
71	0.22
90	0.004
99.5	0.006

In a field test of 82 days duration, aluminum 2S showed a corrosion rate of 0.006 ipy in 99 percent acetic acid vapors at 212-248 degrees F. In another field test of 157 days duration in 98 percent acetic acid, 2 percent water solution at 86 degrees F showed a corrosion rate of less than 0.0001 ipy for aluminum 2S.

The nickel and nickel base alloys, as a class, possess good resistance to corrosion by acetic acid. The materials comprising this class are nickel, Monel, Inconel, the Hastelloy alloys, the Chlorimets, Illium and some other proprietary alloys.

Acetic acid, under conditions most frequently encountered, is only moderately corrosive to nickel. Factors, such as increasing concentration, aeration, temperature, velocity tend to cause higher rates of corrosion of nickel.

The data shown in Table XI illustrate the lowered resistance of nickel to attack in aerated acetic acid solution.

TABLE XI
Laboratory Corrosion Tests in 6% Acetic Acid at 86° F

MATERIAL:	Indicated Corrosion Rate, Ipy	
	Unaerated	Aerated
Nickel	0.003	0.011
Monel	0.002	0.008

Monel is generally a better choice than nickel for many acetic acid applications. The alloy is subject to increase attack in aerated solutions as was shown by the data in Table XI. However, in unaerated acetic acid the corrosion rates do not exceed about 0.005 ipy. The maximum rate of corrosion occurs at about 50 percent concentration at room temperature and falls to about 0.008 ipy in aerated glacial acetic acid. Increased temperatures cause an increase in the rate of corrosion but in boiling acid from 5 percent to 98 percent the rate for Monel was 0.004 ipy. In aerated hot acid the corrosion rate generally exceeds useful limits.

Inconel is usefully resistant to corrosion by dilute solutions under most conditions of aeration and temperature but it is not suitably resistant to attack by hot concentrated solutions as those encountered in concentrating stills. In dilute highly aerated solutions it is superior to Monel or nickel.

The proprietary nickel base alloys, the Hastelloy alloys, the Chlorimets, Illium and others of comparable composition are generally quite resistant to corrosion by acetic acid over the complete range of concentrations and temperatures, the corrosion rates being less than 0.001 ipy. The use of these alloys would be indicated for critical applications and in those cases where the corrosive action of the solution is too severe for those metals or alloys commonly used.

The austenitic stainless steels probably represent the group of alloys most generally used for acetic acid applications. Generally, these alloys as a group are quite versatile with respect to factors such as concentration, temperature, aeration and agitation or velocity. The alloys in this group most commonly used in the past are Types 304, 347 and 316. There should also be included in this group the special highly alloyed stainless steels such as the proprietary alloys, Durimet 20 and Worthite.

TABLE XII[6]
Laboratory Tests of 168 Hours Duration in Boiling Acetic Acid of Various Concentrations

MATERIAL:	Indicated Corrosion Rate, Ipy			
	10 Percent	50 Percent	75 Percent	Glacial
Type 304 S. S.	0.0002	0.0004	0.033	0.027
Durimet 20	<0.0001	0.0002	<0.0001	0.0001

TABLE XIII
Field Corrosion Test in Boiling 99+% Acetic Acid
Three Test Periods—12, 21 and 11 Days Each
Corrosion Rates Shown Are Averages of the Three Tests

MATERIAL:*	Indicated Corrosion Rate, Ipy
Type 304	0.018
Type 321	0.047
Type 347	0.041
Type 308	0.053
Type 310	0.039
Type 316	0.0006

* Percent Compositions of Alloys Tested are as Follows:—

	C	Cr	Ni	Mo	Cb	Ti
Type 304	.05	18.6	8.17	....	....	....
Type 321			Nominal			
Type 347	.06	19.24	11.38	....	.9	....
Type 308	.08	21.4	10.6	....	....	....
Type 310	.14	23.5	17.4	....	....	....
Type 316	.06	19.4	11.7	2.82	....	....

In general, the 18-8 steels are limited primarily by temperature rather than by acid concentration. These alloys will generally show corrosion rates of 0.001 ipy or less in acetic acid up to glacial at room or atmospheric temperature. They are suitable up to about 50 percent acid concentration at temperatures up to 175 degrees F. Above these conditions Type 316 stainless or the special austenitic stainless steels are preferable. The data shown in Table XII illustrate this point.

A further illustration of this point is provided by the data shown in Table XIII.

Attention should be called to the fact that the steel identified as Type 310 possesses a composition slightly under the AISI Specified Range.

It is interesting to note in this case, neither the Types 308 nor 310 stainless steels showed corrosion rates as low as the molybdenum bearing steel Type 316. These data indicate that molybdenum in the alloy is essential for good corrosion resistance in acetic acid. This is further borne out by the data presented in Table XIV.

TABLE XIV
Field Corrosion Test for 82 Days in 99% Acetic Acid Vapors at 212-250° F

MATERIAL:	Indicated Corrosion Rate, Ipy
Type 304	0.066
Type 316	0.003

The 18-8 stainless steels are generally adequate for acetic acid storage service and this is illustrated by the data appearing in Table XV.

TABLE XV
Field Corrosion Test in Acetic Acid Storage at 86-95° F

MATERIAL:	Indicated Corrosion Rates, Ipy	
	24 Percent Acid 115 Days	98 Percent Acid 157 Days
Type 304	<0.0001	<0.0001
Type 316	<0.0001	<0.0001
Type 317	<0.0001	<0.0001

It has been indicated at the outset of the discussion of corrosion by acetic acid, that essentially pure solutions would be considered first and then followed by a discussion of the corrosion by acetic acid solutions containing impurities and/or other organic compounds.

In considering the latter solutions, the conclusion is quickly reached that performance of various materials is likely to differ materially or even drastically from that outlined for the more or less pure acetic acid solutions. This difference in the behavior of various materials of construction cannot always be predicted and it appears to vary with the nature of other chemical compounds present.

One serious corrosion problem is associated with the presence of sodium chloride in acetic acid solutions. The salt can enter the system with process water used for dilution or other purposes. In many cases, small quantities of salt may be sufficient to cause accelerated corrosion of such materials as the stainless steels which otherwise would be suitable. Some data are available to support this fact which are shown in Table XVI.

TABLE XVI
Laboratory Tests on Type 304 S. S. in Various Acetic Acid Solutions Boiling Under Reflux

Test Media:	Indicated Corrosion Rate, Ipy
10% Acetic Anhydride—90% Acetic Acid	0.0033
Same Plus 1% NaCl	0.015
100% Acetic Acid	0.002
99% Acetic Acid Plus 1% NaCl	0.098
0.012% NaCl in Acetic Acid (Unstated Conc.)	0.008
0.024% NaCl in same Solution	0.023

If temperatures are low, serious pitting of the stainless steels may occur, but at higher temperatures the corrosion tends to be even or general in nature but it proceeds at a high rate.

It is noteworthy that sufficient plant experience has proved that the presence of salt can be corrosive and, therefore, it would be a wise procedure to either purify the water or else make sure the chloride content is very low.

Other sources of difficulty are those associated with the production of acetic acid by the alcohol oxidation process or the recovery of acetic acid produced by the destructive distillation of wood. In both these cases, mixtures of organic acids appear to be more corrosive to some alloys and less to others than are the individual acids themselves. An illustration of this point with relation to the recovery of acetic acid from wood pyrolysis in the absence of air is provided by the data shown in Table XVII.

TABLE XVII
Field corrosion test for 1126 days in ethyl acetate-acetic acid azeotrope distillation process. Composition of the solution was 80 per cent acetic acid, 2-3 per cent formic acid, 3-5 per cent propionic acid, ethyl acetate and a small amount of water. Specimens were exposed midway in a 28 plate distillation column. The temperature was 195° F and liquid velocity was 0.7 ft/sec.

MATERIAL:	Indicated Corrosion Rate, Ipy
Copper	0.0011
Silicon Bronze	0.0008
Hastelloy B	0.0074
Hastelloy C	0.0040
Type 316 S. S.	0.04*

* Type 316 test specimens corroded away during test. Rate determined by measuring the residual thickness of specimen holder supporting brackets. Specimens of Monel, Nickel, Inconel, Type 304, Aluminum 2S and Mild Steel corroded away during the test.

In the preparation of acetic acid by the alcohol oxidation process, appreciable quantities of other compounds such as formic acid, acetaldehyde and miscellaneous esters are commonly encountered. Under certain circumstances, the behavior of various metals and alloys is considerably different than otherwise expected.

For example, in the case of formic acid, the performance of the austenitic stainless steels appears to be adversely affected while the behavior of copper and copper base alloys, Monel and nickel appears to be improved. This point is illustrated by the data appearing in Table XVIII.

TABLE XVIII

Field Corrosion Tests in Mixtures of Acetic and Formic Acids at About 220° F

Duration of Tests in All Cases 99 to 129 Days

MATERIAL:	Acetic Acid............. Formic Acid.............	25% 1.5%	25% 4%	30-50% 2-10%
Type 302 S. S.		0.009	a	a
Type 347 S. S.		0.010	0.020	
Type 316 S. S.		0.0010	0.0033	0.020
Type 317 S. S.		0.0003	0.0020	0.011
Monel.		0.0012	0.0006	0.020
Copper.		0.0013	0.0007	0.001
Hastelloy C		0.0006	0.0004	0.007
Worthite.		0.0013	0.0030	0.020

ᵃ Specimens corroded away during test period.

Accumulated experience with mixtures of acetic and formic acid seems to indicate that in hot (above 250 degrees F) solutions containing upwards of 25 percent acetic acid and containing 2 percent or more formic acid, care should be exercised in the choice of materials of construction. The straight 18-8 steels generally are quite poor, the molybdenum bearing austenitic steels are more resistant but these steels may not be as good as the copper group or Monel. It has been observed that in these applications which are critical for Type 316, Type 317 stainless has been found to be almost invariably more resistant and in several instances economically so. It has been observed that for dilute solutions of acetic and formic acids the molybdenum bearing austenitic steels show usefully low rates of corrosion and are superior to the copper group or the nickel base group, with the exception of chromium bearing proprietary alloys.

The presence of high boilers in acetic acid produced by the alcohol oxidation process seems to exert a profound influence on the performance of metals and alloys. It is difficult to evaluate the actual mechanism of the influence but field tests support the conclusion. Such data are shown in Table XIX.

TABLE XIX

A. Field test in middle of fractionation column for 216 days in 75% acetic acid, 20% high boilers, 5% water. Temperature 258° F.
B. Field test in same column as "A" for same 216 day period in top of column in 95% acetic acid 5% higher boilers plus water. Temperature 240° F.
C. Field test made in top tray of fractionating column for 241 days in 99.7% acetic acid at 244° F.

MATERIAL:	A	B	C
Type 316 S. S.	Corroded Away	0.055	0.0017
Type 317 S. S.	0.013	0.012	0.0010
Copper.	0.004	0.004	0.0004
10 Percent Al. Bronze.	0.003	0.004	0.0007
Si Bronze.	0.003	0.004	0.0005
70/30 Cu Ni.	0.004	0.005	0.0006
Type 347.	Corroded Away	Corroded Away	0.014
Monel.	0.003	0.009	0.0015
Nickel.	0.015	Corroded Away	0.0065
Inconel.	0.021	Corroded Away	0.0040
Hastelloy C	0.0003	0.0002	0.0001

These data indicate the superior performance of the copper group in tests A and B. However, in Test C, essentially pure acetic acid, the indicated performance of Type 316 and 317 is good. Hastelloy C also shows good resistance to attack in all three tests.

It is interesting to note that in mixtures of acetic acid and acetaldehydes, the austenitic stainless steels show lower rates of corrosion than the copper group or the non-chromium nickel base alloys. This point is illustrated by the data appearing in Table XX.

TABLE XX

A. Field test for 129 days in 30% acetic acid 0.5% acetaldehyde solution at 100° F. Specimens exposed at top of fractionating tower.
B. Field test for same 129 day period at bottom of same tower as "A" in 30% acetic acid 3% acetaldehyde solution at 110° F.
C. Field test for 112 days at top of fractionating tower in 20% acetic acid, 50% acetaldehyde balance water solution at 210° F.
D. Field test for 255 days at top of tower in 85% acetic acid 8% acetaldehyde, 2% low boilers, 0.1% high boilers, balance water at 235° F.

MATERIAL:	Indicated Corrosion Rate, Ipy			
	A	B	C	D
Type 347 S. S.	0.0001	0.0001	0.0036	
Type 316 S. S.	0.0001	0.0001	0.0007	0.0010
Type 317 S. S.	0.0001	0.0001	0.0002	
Worthite.	0.0001	0.0001	0.0007	
Inconel.	0.0001	0.0001	Corroded Away	
Hastelloy A........	0.035	0.022	Corroded Away	
Monel.	0.043¹	0.019	Corroded Away	
Nickel.	0.027	0.022	Corroded Away	
Copper............	0.045ᵃ	0.021	Corroded Away	0.022²
Hastelloy C........	0.0001	0.0001	0.0007	

¹ Minimum rate—specimens corroded away during test.
² 10 percent aluminum bronze containing 5% nickel and 2.5% iron.

It should be noted that sufficient plant experience is available which indicates that serious intergranular corrosion can occur in heat affected zones adjacent to welds in the austenitic stainless steels in the handling of some mixtures of acetic acid and other organic compounds such as have been discussed. Temperature of the solution is an important factor.

It is interesting to note there are some mixtures of acetic and formic acid wherein the behavior of various materials of construction is somewhat different than in the cases cited above. Such mixtures are those encountered in textile aging. Various field corrosion test results are shown in Table XXI.

TABLE XXI

A. Field test for 150 hours in 6 parts 56% acetic acid and 1 part 90% formic acid condensate at 212° F. Specimens exposed in liquid in bottom of ager.
B. Field test in vapors of "A" at 220° F—150 hours.

MATERIAL:	Indicated Corrosion Rate, Ipy	
	A	B
18–8 S. S.	0.0007*	0.006*
Type 316 S. S.	0.0001	0.0001
Monel.	0.008	0.0008
Inconel.	0.008	0.015
Nickel.	0.011	0.011
Brass.	0.011	0.011
Aluminum.	0.018	0.22

* Specimens seriously pitted during test period.

It is believed the relatively low temperature and the purity of the two acids making up the aging solution are contributing factors leading to the usefully low rates of Type 316 stainless.

In connection with textile agers, an interesting incident occurred involving acetic acid alone. A fire in the mill caused an acetic acid tank to become red hot and to subsequently be quenched by water from a fire hose. About one year later this tank, which was constructed of Type 316, failed. Examination of a sample from the failed tank showed gross intergranular attack. As a matter of fact, the specimen examined consisted only of grains of the stainless loosely held together. There was no ductility whatsoever. A subsequent plant corrosion test showed a rate of 0.0003 ipy for annealed stainless.

Another interesting situation was studied wherein again the actual performance of certain materials of construction varied considerably from their respective expected behavior. This case involved mixtures of acetic acid and salicylic acid. The process involved was the recovery of the acetic acid utilizing a multi-plate Type 316 stainless steel fractionating column. A number of plant tests were made in this column with the results shown in Table XXII.

TABLE XXII

A. Field test for 891 hours in the vapors on tray 8 of the column at 250° F. Composition of liquid on tray 8:—91.68% acetic acid, 0.86% salicylic acid, 7.46% water.

B. Field test for 1530 hours in vapors on tray 17 at 246° F. Composition of liquid on tray 17:—91.86% acetic acid, 0.95% salicylic acid, balance water.

C. Field test for 1380 hours in vapors on tray 24 at 226° F. Composition of liquid on tray 24:—74.66% acetic acid, 0.27% salicylic acid, balance water.

D. Field test for 1380 hours on tray 32 in vapors at 219° F. Composition of liquid on tray 32:—55.5% acetic acid, 0.016% salicylic acid, balance water.

E. Field test for 1380 hours on tray 40 in vapors at 212° F. Composition of liquid on tray 40:—23.44% acetic acid, 0.011% salicylic acid, balance water.

| | Indicated Corrosion Rates, Ipy | | | | |
| | Tray 8 | Tray 17 | Tray 24 | Tray 32 | Tray 40 |
MATERIAL:	A	B	C	D	E
Monel	0.082	0.090	0.066	0.041	0.032
Nickel	0.052	0.093[1]	0.093[1]	0.093[1]	0.093[1]
Inconel	0.038	0.075	0.095[1]	0.095[1]	0.096[1]
Type 304 S. S.	0.009	0.021	0.105[1]	0.025	0.042
Type 316 S. S.	0.0012	0.014	0.032	0.0016	0.0007
Type 317 S. S.	0.0011	0.005	0.010	0.0013	0.0012
Carpenter 20	0.0010	0.005	0.010	0.0017	0.0002
Hastelloy C	0.0002	0.0003	0.0004	0.0004	0.0005
Aluminum 2S		0.033[2]	0.30[3]	0.30[3]	0.31[3]
Aluminum 52S		0.053[2]	0.28[3]	0.28[3]	0.28[3]
Copper		0.087[4]	0.038[4]	0.024[4]	0.10[4]
10% Al. Bronze*		0.10[d]	0.052[d]	0.024[d]	0.14[d]

* Alloy contained 3.5 percent Fe.

[1] Minimum rate—specimen corroded away in 1380 hours.
[2] Rates based on 480 hour exposure period.
[3] Minimum rate—specimen corroded away in 480 hours.
[4] Rates based on 900 hour exposure period.

It is to be observed that Hastelloy C showed very low rates of corrosion in all tests. Type 316 stainless steel showed usefully low rates of corrosion throughout the tower excepting on Trays 17 and 24. Type 317 stainless steel showed usefully low rates of corrosion throughout the tower excepting on Tray 24. Carpenter 20 was not much better than Type 317 stainless, which showed a significant superiority over Type 316 in the more aggressive locations. The copper group, aluminum and the nickel group all showed corrosion rates too high to permit their use.

Based on previously accumulated information on the performance of acetic acid, it would seem the variation in acetic acid content would not cause such a corresponding variation in the performance of Type 316 stainless steel. The data for Tray 24 were verified by actual measurement of loss in metal thickness over a six month period, the rate being 0.036 ipy for 12 gauge Type 316 stainless steel.

A test was made in another Type 316 stainless steel fractionating column used for a finishing still column in the acid recovery process. These data, shown in Table XXIII, indicate the solution was much less corrosive in general for the materials tested than the solution on Tray 8 (Table XXII), for example.

TABLE XXIII

Field test for 1022 hours in vapors at 234° F. Composition is 99.5% acetic acid, 0.05% salicylic acid, 0.45% water.

MATERIAL:	Indicated Corrosion Rates, Ipy
Monel	0.0083
Nickel	0.0053
Inconel	0.0069
Type 302 S. S.	0.015
Type 316 S. S.	0.0041
Type 317 S. S.	0.0030
Carpenter 20	0.0022
Hastelloy C	0.0001

During this investigation, an opportunity presented itself for the study of the behavior of various materials in a hot mixture of acetic acid, salicylic acid vapors at very high velocity. These results are shown in Table XXIV.

TABLE XXIV

Field test for 891 hours in a mixture of 86-91% acetic acid, 8.4% salicylic acid vapors at 260° F and at extremely high velocities. The specimens were exposed in a nozzle between the exit of a heat exchanger and the base of the column.

MATERIAL:	Indicated Corrosion Rate, Ipy
Type 302 S. S.	0.137
Type 316 S. S.	0.034
Type 317 S. S.	0.011 and 0.037
Carpenter 20	0.103
Hastelloy C	0.0008

Very heavy erosion lines were observed on all specimens except Hastelloy C. There were several small incipient locally etched spots and some small pits on the edge of one of the duplicate Hastelloy C
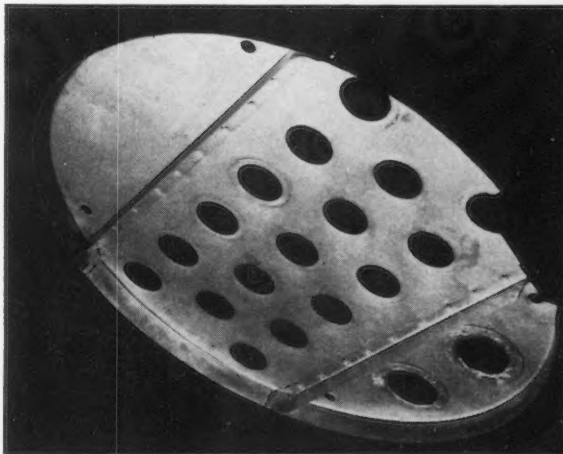
Figure 1—Type 316 stainless steel bubble cap tray No. 27 of a 40-tray acetic acid recovery column.
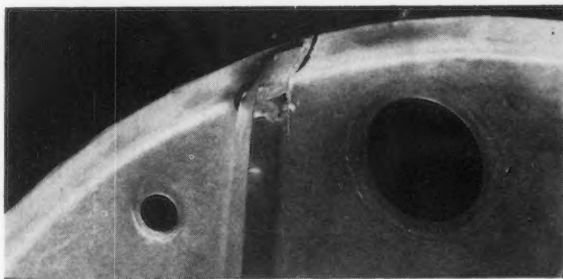
Figure 2—View from upper side of tray No. 27 showing attack in heat affected zone where the weir was welded to tray flange.
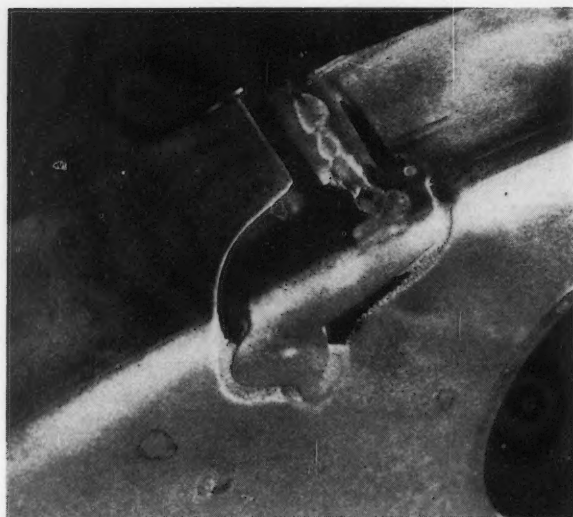
Figure 3—View from underside of tray No. 27 showing attack in heat affected zone where the weir was welded to the tray flange.

specimens. Duplicate specimens of Monel, nickel and Inconel corroded away during the test period.

It should be noted that the corrosive environments which prevail in this acetic acid recovery unit, (especially in the multiplate fractionator) are particularly aggressive to the heat affected zone adjacent to welds in the Type 316 stainless, as illustrated by Figures 1, 2 and 3. A series of tests were made exposing specimens of as-welded Type 316 ELC stainless ¼-inch thick and the weight loss results corresponded well with those shown in Table XX. However, there was very little, if any, attack in the heat affected zones of these welded specimens.

The corrosion problems existing in this particular plant are extremely interesting and the answers are not yet apparent. There are underway additional investigations which, it is hoped, will provide an economical answer to the problem.

C. *Butyric Acid*

In the case of other aliphatic organic acids, some data are available which pertain to the corrosive characteristics of butyric acid. One method of preparation of butyric acid is the oxidation of butyraldehyde. Some tests were made in the distillation of butyric acid so produced. These data are shown in Table XXV.

TABLE XXV

A. Field test for 32 days in butyric acid plus small amounts of water at 230° F. The specimens were exposed in the liquid in the still feed liquor heater.
B. Field test for 32 days, specimens exposed to vapors above liquid in "A."

MATERIAL:	Indicated Corrosion Rate, Ipy	
	A	B
Type 316 S. S.	<0.0001	<0.0001
Type 317 S. S.	<0.0001	<0.0001
Type 310 S. S.	<0.0001	<0.0001
Carpenter 20	0.0001	<0.0001
10 Percent Al. Bronze	0.16	0.048
70/30 Cu Ni	0.095	0.013
Monel	0.050	0.012
Nickel	0.036	0.009
Inconel	0.060	0.015
Hastelloy B	0.0064	0.0025
Hastelloy C	<0.0001	<0.0001

In the light of these data, it appears that Type 316 stainless steel would be a useful material of construction. It is not known how an 18-8 stainless steel would behave but presumably it might be limited, temperature-wise. The copper group and the nickel group, the Hastelloy alloys excepted, show corrosion rates too high to permit their use.

Anhydrides

Of the various organic anhydrides probably the most commercially important are those of acetic, phthalic and maleic acids.

One of the commercial methods of manufacture of acetic anhydride is the pyrolysis of glacial acetic acid. Table XXVI gives the results of corrosion tests in this plant operation.

TABLE XXVI

Field corrosion tests in glacial acetic acid at 1250° F. Vapor velocity 175 ft/sec. Specimens exposed in inlet leg of reaction coil.

MATERIAL:	Indicated Corrosion Rate, Ipy		
	Test A 450 Hours	Test B 1769 Hours	Test C 1384 Hours
Hastelloy C	0.0001 (gain)	0.0001	Not Tested
Type 317 S. S.	0.0004	0.0004	0.0012
Type 316 S. S.	0.0004	0.0006	0.0017
Type 316 ELC	Not Tested	0.0006	Not Tested
Illium	0.0002	Not Tested	Not Tested
Aloyco 20	Not Tested	0.0001	Not Tested
Type 309 S. S.	Not Tested	0.0004	Not Tested
Hastelloy B	0.0003	0.0007	Not Tested
Hastelloy A	0.0033	Not Tested	Not Tested
Inconel	0.13	0.11	Not Tested
Monel	Corroded Away	Not Tested	Not Tested
Nickel	Corroded Away	Not Tested	Not Tested
Type 410 S. S.	Not Tested	Not Tested	0.0015
Type 430 S. S.	Not Tested	Not Tested	0.0012
Type 446 S. S.	Not Tested	Not Tested	0.0002

These data are indicative of good performance of the austenitic stainless steels which is verified by the extensive use of these materials in plant practice. The chromium-iron alloys, namely, Types 410, 430 and 446 may be useful for this service but their respective utility probably would require proof by actual plant test.

Phthalic anhydride is an important organic anhydride and is manufactured by the oxidation of naphthalene. The anhydride can also be prepared by heating the acid to a temperature just above its melting point (375 degrees F). Table XXVII gives rates of corrosion in essentially pure phthalic anhydride at 350 degrees F.

TABLE XXVII

Field corrosion test for 157 days in phthalic anhydride at 350° F. Specimens exposed in heat exchanger.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	<0.0001
Nickel	<0.0001
Inconel	<0.0001
Copper	0.027
Aluminum	0.002*
18-8 Stainless	<0.0001
Type 316	<0.0001
25-12 Cr-Ni Stainless	<0.0001
Hastelloy A	<0.0001
Mild Steel	0.0004†
Ni-Resist	0.0002
Cast Iron	0.0003

* Pitted to depth of .006 inch.
† Pitted to depth of .002 inch.

In the manufacture of phthalic anhydride by the oxidation of naphthalene, one of the methods is the use of sulfur trioxide as the oxidizing agent. Sulfur

dioxide is a by-product and this aggravates the corrosion problem. Data illustrating this point are shown in Table XXVIII.

TABLE XXVIII

Field corrosion test for 330 hours in a mixture of phthalic acid and phthalic anhydride vapors at 430°-550° F. Specimens exposed in the still body.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	0.044
Monel, welded	0.040*
Nickel	0.074
Nickel, welded	0.070*
Inconel	0.033
Inconel, welded	0.036*
Type 302	0.024
Type 304	0.036
Type 316, welded	0.0002—Incipient pitting
Type 316	0.0003—Incipient pitting
Type 347	0.035
Type 317	0.0001
Type 309	0.019
Hastelloy A	0.028†
Copper	0.11

* Slight grain boundary attack along welds. Monel least, nickel next and Inconel the most.

† Attack along grinding wheel marks.

Maleic anhydride is another commercially important chemical and may be prepared by the catalytic oxidation of benzene by air at 400-500 degrees C. Generally those materials which are useful for phthalic anhydride are useful for maleic.

Frequently these two anhydrides are present together, for instance in recovering chemicals in coke by-products industry, naphthalene and benzene are present and when these are oxidized the respective anhydrides are formed. Table XXIX indicates rates of corrosion when sulfur dioxide is present along with the two anhydrides.

TABLE XXIX

Field corrosion test for 1090 hours in mixture of crude phthalic anhydride and maleic anhydride at 400° to 545° F. Vapor velocity 7 ft/sec. Specimens exposed on top tray of fractionating column in vapors.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	0.022
Nickel	0.061
Inconel	0.022
Type 302	0.039
Type 316	0.0007
Type 317	0.0001
Type 310	0.048
Hastelloy B	0.0008
Hastelloy C	0.0001
Worthite	<0.0001

The data in Table XXX illustrate the fact that rather mild corrosive conditions prevail when sulfur dioxide is absent.

TABLE XXX

Field corrosion test for 1709 hours in mixture of pure phthalic and maleic anhydrides vapors at 390°-720° F. Specimens exposed in top of converter.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	0.0002
Nickel	0.0001
Inconel	<0.0001
Copper	0.007
Aluminum	Melted due to high temperature
18-8 Stainless	<0.0001
Type 316	<0.0001
25-12 Cr-Ni Stainless	<0.0001
Hastelloy A	0.0001
Mild Steel	0.001
Ni-Resist	0.001
Cast Iron	0.002

According to the data shown in Table XXXI the molybdenum bearing austenitic stainless steels and

also the special austenitic alloys show good resistance to corrosion by mixtures of acetic acid and acetic anhydride.

TABLE XXXI

Plant corrosion test for 140 days in a mixture (unstated composition) of 50% acetic acid, 50% acetic anhydride plus some peracetic acid at 226° F. Specimens were exposed in the liquid header of the fractionating column reboiler.

MATERIAL:	Indicated Corrosion Rate, Ipy
Type 316 S. S.	0.0005
Type 317 S. S.	<0.0001
Carpenter 20	0.0005
Nickel	0.031

In this test, specimens of 70/30 cupro-nickel, Types 304, 347 and 430 stainless steels and Monel were missing after exposure, probably having corroded away.

II—Aldehydes

The aldehydes comprise a group of interesting organic chemicals from the viewpoint of corrosion. If the aldehydes are very pure, they would not be expected to be corrosive. Commercially pure aldehydes generally are not particularly corrosive. However, aldehydes less pure, i.e. containing appreciable impurities, are liable to cause corrosion of such a magnitude as to require the careful attention of a materials engineer.

The reason the impure aldehydes are somewhat troublesome is probably due to the presence of an organic acid. Aldehydes are subject to ready oxidation, the oxidation product being the corresponding acid, i.e. acetaldehyde—acetic acid. The fact that aldehydes are readily oxidizable is the basis of commercial production of several important organic acids.

Some work has been done on the effects of metals on formaldehyde under storage conditions. The formaldehyde used in the tests was colorless but initially had an acidity of 0.034 percent calculated as formic acid. Color evaluations were made after storage periods of seven, thirty and sixty days and at the end of the sixty day period, acidities were determined. These laboratory observations are shown in Table XXXII.

TABLE XXXII

Effects of Metals on Storage Stability of Formaldehyde

MATERIAL:	Color After Seven Days	Color After Thirty Days	Color After Sixty Days	Acidity After Sixty Days
Monel	Very Sl. Yellow	Sl. Yellow	Sl. Yellow	0.055%
Nickel	OK	Very Sl. Yellow	Very Sl. Yellow	0.037%
Inconel	OK	OK	Very Sl. Yellow	0.039%
Type 302 S. S.	OK	OK	OK	0.034%
Type 304 S. S.	OK	OK	OK	0.037%
Type 316 S. S.	OK	OK	Sl. Yellow	0.037%
Aluminum 2S	Very Sl. Yellow	Sl. Yellow	Sl. Yellow	0.170%
Copper	OK	Green Tint	Greenish Blue Sludge	0.083%
Mild Steel	Yellow in two Days	Yellow	Yellow	0.221%
Wrought Iron	Dark—8 Hrs.	Dark Yellow	Dark Yellow Sludge	0.282%
Blank	OK	OK	OK	0.034%

In addition to the above investigation, a sixty day corrosion test in the same formaldehyde solution was made using insulated specimens in a suitable holder. These results are shown in Table XXXIII.

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TABLE XXXIII

Corrosion test in formaldehyde for 60 days at room temperature.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	Less than 0.0001 ipy
Nickel	Less than 0.0001 ipy
Inconel	Less than 0.0001 ipy
Type 302	Sl. gain in weight
Type 304	Sl. gain in weight
Type 316	Sl. gain in weight
Aluminum 2S	0.0010
Copper	0.0002
Mild Steel	0.0015
Wrought Iron	0.0027

The data of Table XXXIII indicate that carbon steel would be expected to show an economical service life. However, the data of Table XXXII indicate that carbon steel would not be serviceable from the viewpoint of formaldehyde stability or product contamination. Thus is illustrated a point which often comes up regarding service life versus product contamination. This is further exemplified by the data shown in the two tables for copper, aluminum and to some extent Monel.

There is an important point involved here in that the formaldehyde initially contained some small quantities of acid, probably formic acid. There would be expected, therefore, some attack on the more susceptible metals or alloys, e. g. copper, iron, aluminum, Monel. The resulting corrosion product would introduce metal ions which would tend to catalyze the oxidation of the formaldehyde to formic acid with the subsequent introduction of additional metal ions in solution.

As a result of this study several things which may be done to minimize the oxidation of aldehydes, particularly during storage, were revealed. Some of these suggestions are as follows:

1. Decrease contact of the aldehyde with air either surface-wise or time-wise.
2. Keep temperatures to a minimum value consistant with the compound.
3. Neutralize the acid as it is formed.
4. Utilize an oxidation inhibitor.
5. Utilize materials of construction more resistant to corrosion or one which yields corrosion products which do not function as oxidation catalysts.

TABLE XXXIV

Corrosion Tests in Formaldehyde Solutions

A. Field test for 28 days in a mixing tank containing a solution of 40% formaldehyde, 10% methanol, 0.01% formic acid, 50% water. The temperature was 122° F, there was moderate aeration and agitation.

B. Field test for 87 days in a storage tank containing a solution of 37% formaldehyde and less than 1% free methanol, balance water. No acid content values were given. Temperature 96° F average, air was used once a day (15-30 minutes) for agitation to achieve thermal uniformity.

C. Field test for 31 days in formaldehyde vapors at a temperature of 148° F (dry bulb). Considerable aeration and slow vapor velocity.

	Indicated Corrosion Rate, Ipy		
MATERIAL:	Test A	Test B	Test C
Monel	0.0056	0.0044	<0.0001
Nickel	0.0083	0.0014	<0.0001
Inconel	0.0001	0.0001	<0.0001
Type 302 S. S.	0.0001	0.0001	<0.0001
Type 304 S. S.	0.0001	0.0001	<0.0001
Type 316 S. S.	0.0001	0.0001	<0.0001
Copper	0.0020	0.0038	....
Mild Steel	0.022	0.019	....
Aluminum 2S	0.0014	0.0087	<0.0001
Hastelloy C	0.0001	....	....
Durimet T	0.0005	....	....
Cu Free Ni-Resist	0.0057	....	....
Cast Iron	0.026	....	....
Aluminum 52S	....	....	<0.0001
Block Tin	....	....	<0.0001

Of course, there should be a practical or reasonable attitude prevailing as to tolerance limits of aldehyde oxidation compared to corrosion rates and service life of equipment.

The corrosion behavior of several metals and alloys in formaldehyde solutions and vapors is illustrated by the data shown in Table XXXIV.

These data indicate that the austenitic stainless steels as a group probably represent first choice and copper and nickel-base alloys suitable second choices. The fact that the solutions were aerated (Tests A and B) is probably the reason for the relatively higher rates of corrosion of copper, Monel, nickel, mild steel, etc. Aeration would not be expected to be an important factor in the case of vapors (Test C). Aluminum probably would find somewhat limited application because of its susceptibility toward rapid corrosion by formic acid, as outlined earlier in the paper.

The various aldehydes are encountered in the chemical industry, particularly during the manufacture of aldehydes and/or acids by the oxidation of alcohols. Generally speaking, these solutions are not particularly corrosive if the acid content and oxygen content are low. This point is illustrated by the data shown in Table XXXV.

TABLE XXXV

A. Field test for 138 days in reboiler at 245° F average. Solution composed of 2% formaldehyde, 0.2% formic acid plus small quantities of methanol, ketones and other aldehydes. No aeration and considerable agitation.

B. Field test for 87 days in bottom of fractionating tower. Average temperature 243° F, no aeration, rapid agitation. Solution composed of 10% formaldehyde, traces of formic acid, calcium formate and some glycols.

C. Same as "B," specimens exposed on tray at center of the tower. Temperature 220° F. Solution essentially 10% formaldehyde.

D. Field test for 71 days on second tray from top of fractionating tower. Temperature 275° F, no aeration, rapid agitation, solution essentially 20% formaldehyde. Also present 10-15% volatiles, acetone, and 0.1% formic acid.

E. Field test for 125 days in reboiler vapor line of evaporator used to concentrate formaldehyde. Concentration 65-75% formaldehyde, temperature 150° F, no aeration and rapid agitation.

Material:	Test A	Test B	Test C	Test D	Test E
Monel	0.0001	0.0002	0.0005	0.0043	0.0005
Nickel	0.0003	0.0002	0.0009	0.0022	....
Inconel	0.0006	0.0001	0.0022	0.030	....
Type 347 S.S.	0.0002	0.0004	0.0001	0.0008	<0.0001[2]
Type 316 S.S.	0.0001	0.0010[1]	0.0006[1]	0.0001	<0.0001
Type 317 S.S.	0.0001	0.0001	0.0001	0.0001	....
10% Al Bronze	0.0001	....	....	0.0005	....
Sb. Admiralty	0.0003	....	....	0.0004	0.0007[3]
Copper	0.0003	0.0005	0.0005	0.0002	....
70/30 Cu Ni	0.0001	....	....	0.0004	....
Si Bronze	0.0001	....	....	0.0004	....
Hastelloy C	0.0001	0.0001	0.0001	0.0001	....
Worthite	....	0.0001	0.0001	....	....
Carbon Steel	....	....	....	....	0.032
Aluminum 61ST	....	....	....	....	0.0002

[1] Final weights checked. Initial weights may not have been accurate.
[2] Type 304 Stainless Steel.
[3] Arsenical Admiralty.

The rates for Monel, nickel and particularly Inconel are conspicuously high in Test D as compared with Tests B and C. The reason for this is not apparent but may be associated with the somewhat higher temperature. It is important to note at the same time, however, that the rates for copper are essentially of the same order of magnitude in both Tests C and D.

Field corrosion tests serve to indicate other aldehydes such as acetaldehyde and butyraldehyde are essentially non-corrosive when comparatively free of organic acid content. These data are shown in Table XXXVI.

TABLE XXXVI

Corrosion Tests in Acetaldehyde and Butyraldehyde

A. Field test for 129 days in 98% acetaldehyde and 2% low boiling material. Temperature 135° F average. Specimens exposed at top of the tower. No aeration.

B. Field test for 136 days in 98% butyraldehyde, 0.7% butyric acid and 1.3% water. Temperature 65° F average. Specimens exposed in storage tank alternately exposed to liquid and vapors.

MATERIAL:	Indicated Corrosion Rate, Ipy	
	Test A	Test B
Monel	0.0005	0.0001
Nickel	0.0007	0.0001
Inconel	0.0001	0.0001
Type 304	0.0001	0.0001
Type 316	0.0001	0.0001
Type 317	0.0001	0.0001
Aluminum 3S		0.0001
Worthite	0.0001	......
Hastelloy C	0.0001	......
Copper	0.0018	......

It is important to note that butyraldehyde, at least, seems to be appreciably more susceptible to oxidation than acetaldehyde or formaldehyde. It is reported[7] that pure butyraldehyde left standing in contact with air is partly oxidized, to butyric acid. In one experiment when air was bubbled into butyraldehyde under a reflux condenser and at ordinary temperature, 36.5 percent of the aldehyde was oxidized to butyric acid in six hours. It is also reported manganese and cobalt salts catalyze the oxidation reaction.

It is further reported[8] that copper is rapidly attacked by butyraldehyde in the presence of air, forming a greenish-blue solution. The mechanisim of the attack is probably the parallel formation of small amounts of butyric acid and copper oxide with a subsequent solution of the copper oxide in the butyric acid.

In many cases care should be exercised in the handling of the butyraldehyde since the grade available commercially contains some butyric acid, i.e. of the order of 0.5 percent. This amount of acid is probably sufficient in some instances to cause discoloration of the aldehyde by contamination of corrosion products due to the reaction of the acid with the material of construction.

It is to be noted in passing that nickel clad steel tank cars have been used for shipping butyraldehyde for several years. No difficulties have been encountered due to corrosion of the nickel by the aldehyde.

Evidence has been presented above that aldehydes are not particularly corrosive provided the quantity of the appropriate organic acid present is not appreciable. In those cases where the acid is present in appreciable quantities, the resultant effect can be quite severe. This point is illustrated for formaldehyde-formic acid by the data appearing in Table XXXVII.

These data indicate the copper and copper-base alloys represent fairly good first choices with Monel a good second choice. The austenitic stainless steels and Inconel are conspicuous by their essentially poor resistance to corrosion by this mixture.

In the case of acetaldehyde-acetic acid mixtures, the molybdenum bearing austenitic stainless steels, according to the data shown in Table XXXVIII, appear to be superior to the copper base alloys. However, the indications are that the corrosion resistance

of Type 316 stainless is decreased to some extent while that of the copper base group is improved with increasing acetic acid content. It is acknowledged a portion of the reported trends may be due to the higher temperature involved in Test B. It is interesting to note the superiority of Type 317 stainless over its somewhat lower alloyed counterpart Type 316.

TABLE XXXVII

Corrosion Test in Formaldehyde-Formic Acid Solution

Field test for 27 days in 12-15% formaldehyde and 2% formic acid solution at 275° F. Specimens exposed on feed tray of fractionation tower. No aeration and extensive agitation.

MATERIAL:	Indicated Corrosion Rate, Ipy
70/30 Cu Ni	0.0006
Copper	0.0008
10 Percent Al Bronze	0.0007
Sb. Admiralty	0.0012
Silicon Bronze	0.0013
Monel	0.0075
Nickel	0.011
Type 317	0.040
Inconel	0.066
Type 316	0.073
Type 304	Specimen Corroded Away[1]
Type 347	Specimen Corroded Away[1]
Mild Steel	Specimen Corroded Away[2]

[1] Specimens 0.031″ thick weighing about 16 grams.

[2] Specimens 0.062″ thick weighing about 30 grams.

TABLE XXXVIII

A. Field test for 73 days in 85% acetaldehyde—3% acetic acid mixture at 170° F. 12% various low boilers also present. Specimens exposed at top of fractionating column. No aeration.

B. Field test for 187 days in 70% acetaldehyde—15% acetic acid mixture at 245° F. 0.3% formic acid also present. Specimens exposed at top of fractionating column. No aeration.

MATERIAL:	Indicated Corrosion Rate, Ipy	
	A	B
Type 317 S. S.	......	0.0007
Type 316 S. S.	0.0001	0.0046
8 Percent Al Bronze	Spec. Corroded Away	0.017
85-15 Red Brass		0.030
As. Admiralty	0.094	0.030
70/30 Cu Ni	0.080	0.038
Silicon Bronze	0.081	......
Monel	0.087	......

In the concluding portion of the aldehyde section of the paper, there are presented some data showing the corrosive nature of mixtures of aldehydes, organic acids and inorganic acids, the latter being sulfuric. In this case, formaldehyde was being polymerized to trioxane through the use of sulfuric acid as a catalyst. The data shown in Table XXXIX indicate the effect of this mixture on several commonly used materials of construction.

TABLE XXXIX

Corrosion Tests in the Trioxane Reaction

A. Field test for 30 days in the liquid in a reactor containing a mixture of 40-60% formaldehyde, 1-4% formic acid and 1-3% sulfuric acid. The temperature was 222° F, no aeration but violent agitation due to ebullition.

B. Same as "A" except specimens exposed to vapors above the liquid.

MATERIAL:	Indicated Corrosion Rate, Ipy	
	A	B
Monel	0.0012	0.0013
Nickel	0.0023	0.0033
Chem. Lead	0.0036	0.0025
Inconel	0.010	0.0047
Type 316 S. S.	0.026	0.017
Type 302 S. S.	0.022	0.024

These data show Monel to be quite serviceable with nickel and chemical lead useful second choices with the preference of either of the latter based primarily on fabricability. The austenitic stainless steels

show rates of an uneconomic magnitude. Reference should be made here to the corrosion rate shown for Monel in Table XXXVII (0.0075 ipy) in a mixture of 12-15 formaldehyde—2 percent formic acid at a somewhat higher temperature. The two rates appear to compare favorably.

III—Ketones

Ketones, considered as a group, are not appreciably corrosive to commonly used materials of construction including carbon steel. Remler[9] found this to be essentially true in studies he made concerning metals useful for handling organic solvents such as acetone. Some of the results of his tests are shown in Table XL.

TABLE XL
Corrosion of Metals and Alloys
Exposed to C. P. Acetone

MATERIAL:	Test A Spec. Exposed One Month to Boiling Acetone Vapors	Test B Spec. Exposed Six Months to Acetone at Room Temperature
Aluminum 2S	<0.0001 ipy	<0.0001 ipy
Copper	<0.0001 ipy	<0.0001 ipy
Phosphor Bronze	—0—	Sl. Gain
Manganese Bronze	—0—	Sl. Gain
Monel	—0—	Sl. Gain
Nickel	—0—	Sl. Gain
Zinc	—0—	<0.0001 ipy
C. Steel	0.0001 ipy	—0—
Cast Steel	Sl. Gain	<0.0001 ipy

In the handling of the various ketones, if corrosion problems are encountered, it would be well to look for minor constituents or impurities. These probably would be found to be responsible for the corrosion observed.

IV—Alcohols

Alcohols, by themselves, are relatively innocuous to many metallic materials of construction. Carbon steel is usually adequate. This lack of aggressive corrosive characteristics is indicated by Remler[10] in his studies with C. P. methyl alcohol. Some of the results of his investigation are shown in Table XLI.

TABLE XLI
Corrosion of Metals and Alloys
Exposed to C. P. Methyl Alcohol

MATERIAL:	Test A Spec. Exposed One Month to Boiling Menthol Vapors	Test B Spec. Exposed Six Months to Menthol at Room Temperature
Aluminum 2S	<0.0001	Sl. Gain
Copper	Sl. Gain	<0.0001
Phosphor Bronze	Sl. Gain	<0.0001
Manganese Bronze	Sl. Gain	<0.0001
Monel	Sl. Gain	Sl. Gain
Nickel	Sl. Gain	—0—
Zinc	<0.0001	<0.0001
C. Steel	0.0004	—0—
Cast Iron	0.0006	<0.0001

Some slight corrosion problems are encountered in the handling of crude alcohol mixtures which may contain small quantities of corrosive chemicals. This is illustrated by the data shown in Table XLII.

In alcoholic solvent recovery systems, the corrosion problems are generally not severe. However, in some systems, contaminants may be present which originate with the material from which the solvent is being recovered. In these cases it would be well to investigate such sources if corrosion problems are encountered. The results of a test, shown in Table XLIII, indicate some solvent recovery systems do not show corrosive characteristics.

TABLE XLII
Corrosion Tests in Distillation of Some Alcohols

A. Field test for 80 days in distillation of crude methanol. Temperature 180° F. Specimens exposed in lower section of kettle.

B. Field test for 181 days in continuous distillation of ethyl alcohol. Solution comprised of 42% ethyl alcohol 1.4% sulfuric acid, 1.5% acetic acid, 2.3% ethyl acetate, 53% water. Temperature 175-215° F, average 185° F. Specimens exposed to liquid.

C. Field test for 78 days in continuous distillation of ethyl alcohol solution consisting of 9% ethyl alcohol, 91% water, traces of acetic and sulfuric acid. Specimens exposed to vapors in kettle.

MATERIAL:	Indicated Corrosion Rate, Ipy		
	Test A	Test B	Test C
Monel	0.0003	0.0007	0.0024
Nickel	0.0004	0.009	0.0060
Inconel	0.0003	0.0100	0.0054
Copper	0.009	0.0016	0.0050
Silicon Bronze	0.0022	0.0021	0.0050
Type 304 S. S.	0.0001	0.0061	0.0018
Type 316 S. S.	....	0.0072	0.0005
Aluminum	0.0020	....	....
Mild Steel	0.013	....	....
Cast Iron	0.012	....	....
Ni-Resist	0.004	....	....

TABLE XLIII
Corrosion Test in Alcoholic Solvent Recovery

Field corrosion test for 225 days in weak solvent tank. Solvent solution consists of 25% ethyl alcohol, 5-8% acetone, 1-2% ethyl acetate, balance water. Temperature 40-70° F.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	<0.0001
Nickel	<0.0001
Inconel	<0.0001
Type 304 S. S.	<0.0001
Type 316 S. S.	<0.0001
Copper	0.0007
Mild Steel	0.0086
Cast Iron	0.011
Ni-Resist	0.0080

During the production of alcohol, such as by the hydrolysis of unsaturated hydrocarbons using sulfuric acid, corrosion problems are frequently encountered. In one instance in the production of ethyl alcohol, a corrosion test was made in the alcohol reboiler for the rectification column. The results are shown in Table XLIV.

TABLE XLIV

Field corrosion test for 264 hours in reboiler of a rectification column used for the recovery of ethyl alcohol made by the sulfuric acid process using copper sulfate as a catalyst. The solution consisted mainly of alcohol and water plus about 2.5% sulfuric acid and 0.1% copper sulfate. Temperature range 200-250° F.

MATERIAL:	Indicated Corrosion Rate, Ipy
Monel	0.0028
Nickel	0.0059
Inconel	0.020
Type 302 S. S.	0.073
Type 316 S. S.	0.020
Type 317 S. S.	0.019
Type 347 S. S.	0.074
Hastelloy A	0.016
Hastelloy C	0.0082
Worthite	0.0082
Copper	0.0006

The high rates of corrosion of the austenitic stainless steels are caused by the high temperature of the solution containing sulfuric acid and also the fact there is not enough copper sulfate present to inhibit the action of the media on these alloys.

V—Esters

Organic esters themselves are generally innocuous to the commonly used materials of construction. Unless stringent color specifications are involved, carbon steel probably would be found adequately resistant to attack by the esters.

The presence of small quantities of mineral acids will cause hydrolysis of the ester. In such cases, the corrosion problems which may arise would be traceable to the presence of the organic acid and/or the mineral acid. Obviously, in the case of an alkali catalyst causing hydrolysis, saponification would result. Under these circumstances, the amount of corrosion probably would not be severe.

For the low molecular weight esters, hydrolysis will proceed slowly without the presence of a catalyst. Thus, corrosion problems could arise caused by the presence of the free organic acid.

In both these cases, hydrolysis is increased as the temperature is raised, hence, this point should be borne in mind in the event corrosion is encountered.

In esterification reactions, corrosion problems which arise are associated either with the organic acid or the mineral acid used as a catalyst or both. Corrosion data illustrating the fact that the organic acid is probably the principal corrodent are shown in Table XLV, Parts A, B and C.

TABLE XLV—PART A

Field corrosion test in still body producing ethyl acetate. Mixture consists of 70% ethyl alcohol, 20% acetaldehyde, 0.5% acetic acid, water 9%, sulfuric acid 0.1%. Temperature range 77-215° F. Duration of test 8 days.

MATERIAL:	Indicated Corrosion Rate, Ipy
Type 316 S. S.	0.0001
Type 304 S. S.	0.0001
Monel	0.0052
Nickel	0.0058
Inconel	0.0070
Copper	0.0093
Mild Steel	0.092

TABLE XLV—PART B

Field corrosion test in reaction vessel producing ethyl acetate. Mixture consists of 30% ethyl alcohol, 34% acetic acid, 34% ethyl acetate, water 1%, sulfuric acid 0.5%. Temperature range 212-300° F for seven 8 hour periods or 56 hours of total exposure period of 211 hours. Balance of time, 155 hours, reaction cooled to room temperature.

MATERIAL:	Indicated Corrosion Rate, Ipy
Type 316 S. S.	0.0010
Type 304 S. S.	0.0015
Inconel	0.004
Nickel	0.006
Type I Ni-Resist	0.007
Aluminum 2S	0.008
10 Percent Al Bronze	0.012
Monel	0.016
Red Brass	0.034
Copper	0.039

TABLE XLV—PART C

Field corrosion test in reaction vessel producing amyl acetate. Charging mixture consists of 44% glacial acetic acid, 34% amyl alcohol, 2% sulfuric acid, 20% water. Temperature range 70° F to 300° F max. Duration of test 76 days.

MATERIAL:	Indicated Corrosion Rate, Ipy
Type 316 S. S.	0.0004[1]
Type 304 S. S.	0.0037[2]
Monel	0.029
Copper	0.055
Mild Steel	0.15

[1] Specimens pitted 0.004″ in 76 days.
[2] Specimens pitted 0.006″ in 76 days.

In this case, the general magnitude of corrosive attack is indicative of the influence of the organic acid.

Corrosion data illustrating the fact that the mineral acid used as a catalyst has a significant effect on the corrosion of various metals and alloys in esterification reactions are shown in Table XLVI.

TABLE XLVI

Field test in still body producing ethyl acetate. Concentration of acetic acid and ethyl alcohol present in reaction mixture not given. Small quantities of sulfuric and hydrochloric acid used as catalysts. Temperature range 175-215° F. Duration of test 31 days.

MATERIAL:	Indicated Corrosion Rate, Ipy
Silicon Bronze	0.003
Copper	0.003
Monel	0.004
5 Percent Al Bronze	0.004
70/30 Cupro-Nickel	0.005
Inconel	0.036
Type 304 S. S.	Specimens Corroded Away
Type 316 S. S.	Specimens Corroded Away
Type 430 S. S.	Specimens Corroded Away

These data indicate that hydrochloric acid even when present in small quantities is sufficiently corrosive to the stainless steels to preclude their use for an esterification reaction which otherwise is not appreciably corrosive to these alloys.

The corrosion data shown in Table XLVII serve to illustrate the fact that the esters, once formed, are relatively innocuous to many materials of construction.

TABLE XLVII

A. Field test 231 days in vapors at the top of a crude amyl acetate rectification column. The feed mixture consisted of amyl acetate, amylene, water and traces of amyl chloride. Temperature 100°-300° F, average 250° F.

B. Same as "A" above except test made in liquid at the bottom of the column.

MATERIAL:	Indicated Corrosion Rate, Ipy	
	Test A	Test B
Monel	0.0005	0.0002
Nickel	0.0005	0.0001
Inconel	0.0001	0.0001
Type 304 S. S.	0.0001	0.0001
Type 316 S. S.	0.0001	0.0001
Hastelloy A	0.0009	0.0001
Ni-Resist	0.0016	0.0021
Cast Iron	0.0040	0.0056
Mild Steel	0.010	0.0060
Copper	0.0009	0.0006
Aluminum 2S	0.007 (a)	Corroded Away
13 Percent Aluminum Bronze	0.072	0.027
Worthite	0.0001	0.0001

In passing, one of the interesting results of these two tests is the relatively high rate of corrosion occurring on both 2S aluminum and the 13 percent aluminum bronze alloy. Apparently these corrosive conditions are specific to aluminum, hence, in a two phase copper-aluminum alloy some selective corrosion of the aluminum must have occurred. It is interesting to speculate about how a 5 percent aluminum bronze, for example, would have performed under these conditions.

Conclusion

In the discussion of the behavior of various metals and alloys in some organic acids and other related organic compounds, an attempt has been made to point out a few cases where useful applications of certain metals or alloys will result. Generally the choice of a material of construction is not too difficult providing an earnest study is made of the problem. This study may involve plant or laboratory corrosion tests or other types of investigation. It should include not only the study of the corrosion resisting proper-

ties of the metal or alloy but it also should include a study of other important properties such as weldability, mechanical and physical characteristics and other similar properties.

Whatever the course of action it should be realized that hasty material specification may result in early equipment failure. On the other hand if the material specification is based upon a careful study of the problem, an economical service life is the likely reward.

Acknowledgment

References

1. H. H. Uhlig. "The Corrosion Handbook," John Wiley & Sons, New York. Pp. 45 and 759 (1948).
2. "Hastelloy—High Strength Nickel Base, Corrosion-Resistant Alloys." p. 13, Seventh Edition, Copyright 1950—Union Carbide & Carbon Corp.
3. H. S. Rawdon and E. C. Grosbeck, Bureau of Standards Paper No. 367.
4, 5 and 6. M. G. Fontana. *Ind. & Eng. Chem.,* 40, No. 7, 73A, 74A (1948).
7. R. E. Kirk and D. F. Othmer. Encyclopedia of Chemical Technology, Vol. 2, p. 685.
8. Ibid, p. 687.
9 and 10. R. F. Remler. "Metals for Use in Handling Organic Solvents," *Chem. and Met. Eng.,* 30, No. 13, 511-512 (1924).

Appendix I

Annotated Bibliography of Some Literature References Pertaining to Corrosion of Metals and Alloys by Organic Acids.

Corrosion Reporter—Handling Acetic Acid. *Chem. & Met. Eng.* 52, No. 9, 209-210 (1945) Sept. Extensive use of stainless steel 18-8 for glacial acetic acid. For other concentrations, Pb pipes are used, since concern is not handling food and attack is not extensive enough to warrant expense of other materials. Corrosion at cold end of distilling pipes is explained. Use of a few feet of Ag pipe at critical point solved problem.

Acetic Acid vs. Materials of Chemical Plant Construction I and II. Corrosion Forum. *Chem. Eng.* 53, No. 11, 253-254, 256, 258, 260, 262, 264. No. 12, 205-206, 208, 210, 212, 214, 216, 218, 220 (1946) Nov., Dec.; 54, No. 5, 241-242, 244, 246 (1947) May. Symposium by manufacturers evaluating their product for acetic acid service. Articles as follows: Carbon, Graphite, Karbate, by E. S. Malkin (National Carbon Co.) Aluminum Alloys, by E. D. Verink, Jr. (Alcoa) Durimet and Chlorimet, by W. D. Staley (Duriron Co.) Glass Lined Steel, by O. I. Chormann (The Pfaudler Co.) Silver, by L. C. Burman (Baker & Co., Inc.) Stainless Steel (Allegheny Ludlum Steel Corp.) Tantalum, by F. L. Hunter (Fansteel Metall. Corp.) Chemical Porcelain, by J. S. Chowning (Lapp Insulator Co.) Worthite, by W. E. Pratt (Worthington Pump & Mach. Corp.) Haveg, by E. P. Mampe (Haveg Corp.) Lead, by H. M. Church (Lead Industries, Assoc.) High-silicon Iron, by W. D. Staley (Duriron Co., Inc.) Chemical Stoneware, by F. E. Herstein (Gen. Ceramics & Steatite Corp.) Rubber Lining, by O. S. True (U. S. Rubber) Nickel, Nickel Alloys, by W. Z. Friend (Inco) Hastelloy, by C. G. Chisholm (Haynes Stellite Co.)

Corrosion. M. G. Fontana. *Ind. Eng. Chem.,* 40, No. 7, 73A-74A (1948) July. Materials of construction for making and handling acids and actual plant problems are discussed. The best materials for the manufacture of acetic acid are Cu, Bronze, Al, 18-8 stainless, and 18-8 Mo steel, Durimet 20, Ni, Ni alloy, Duriron, Hastelloy C, Chlorimet 3. Hot 75 percent acetic acid badly corrodes both 18-8's but not Cu. Ni and Monel are used if the temperature is below the acid's boiling point and for glacial Acetic acid. These alloys are susceptible to attack under oxidizing conditions. Hastelloy C and Chlorimet 3 are used for hot acetic acid where

severe corrosion exists and the cost of these materials is then justified.

Corrosion. M. G. Fontana. *Ind. Eng. Chem.,* 40, No. 8, 71A-72A (1948) Aug. Plant problems involving equipment failures in the handling of hot acetic acid are described. To reduce the corrosion of heat exchangers Cu was reduced by using nascent hydrogen to reduce the cupric ion. High alloy stainless steel valves and pumps were not satisfactory for corrosion resistance. Type 316 stainless steel was not satisfactory for the separating of vinyl acetate from glacial acetic acid. Stainless steel was recommended by Inco from their corrosion data, however, this was not obtained under the high temperature conditions at which the pumps operated. Vapor absorbers of Type 316 Cb have given excellent service. These valves are cast iron.

Corrosion Reporter. *Chem. & Metall. Eng.* 52, No. 4, 171-172, 174, 176, 178 (1945) Apr. Stainless steel Type 316 still bottoms corroded when NaCl was added to amines or ketones being handled. Na acetate was substituted successfully. Except for corrosion at weld points, stainless Type 316 is successful for equipment used in vaporizing glacial acetic acid and phenyl-acetic acid.

Dissolution of Carbon Steel in Aliphatic Monocarboxylic Acids. V. D. Yakhontov, *Zhurnal Prikladnoi Khimii* (J. Appl. Chem. USSR), 21, No. 6, 667-675 (1948). Experimental study of dissolution of carbon steel in formic, acetic, propionic, butyric and valeric acids. Data on effect of acid concentration and acid temperature on dissolution of steel is given.

Corrosion Reporter—Equipment for Food and Pharmaceutical Products. *Chem. & Met. Eng.* 52, No. 9, 211-212 (1945) Oct. Pb has been completely replaced by stainless steel in one plant where edible acids (citric, tartaric, gluconic and ascorbic) are manufactured. Type 316 is preferred. In a reducing environment or in the presence of sulfides, Type 316 is preferable to Monel. Otherwise stainless and Monel are used interchangeably to handle any concentration of these acids up to 120 degrees C. Hastelloy C pumps are used with 35 percent HCl. A stainless steel tank and agitator in a plant producing activated C were corroded to uselessness in very short order, and rubber-covered or lined steel is now used.

Action of Organic Acids on Stainless Steel. C. F. Poe and E. M. Van Vleet (Univ. Colo.), *Ind. Eng. Chem.,* 41, No. 1, 208-210 (1949) Jan. Contamination of foods on stainless steel cooking utensils is unlikely since only small amounts of Cr and Ni are dissolved. Experiments conducted to determine corrosive action of organic acids commonly found in foods on 18-8 stainless steel showed that the most rapid attack by acids occurs during first 24 hours. Boiling temperatures usually decrease corroding action of acids on stainless steel, especially in 0.01N strength. Strips of steel resist corroding action of most dilute organic acids at 25 degrees C and at boiling temperatures, with exception of boiling oxalic acid in normal concentration. Corrosive activity of organic acids on stainless steels is not, in most instances, a direct function of their concentrations. Tables show loss in weight of stainless steel strips in dilute acids boiled in 30 minutes daily and in dilute acids at 25 degrees C.

Corrosion Tests in the Processing of Soap and Fatty Acids. W. Z. Friend and J. F. Mason, Jr. (Inco). Paper before NACE, 5th Ann. Conf., Cincinnati, April 11-14, 1949. *Corrosion,* 5, No. 11, 355-368 (1949) Nov. A summary of the results of corrosion tests made in operating equipment in soap and fatty acid plants during the past 10 years, using mostly the spool type testing device. Tests in the boiled soap process and glycerine recovery include those in soap kettles, caustic storage, brine tanks, acid and alkali treatment and filtering of soap lye, salt-glycerine slurry, salt-glycerine evaporators and glycerine stills, glycerine bleaching and storage. Tests in fatty acid processing include those in Twitchell and high temperature water splitting of fats, acid washing of fats and fatty acids, deodorization, heating and distillation of animal and vegetable fatty acids including tall oil, fatty acid storage. Tests included a wide variety of materials such as Ni, Monel, Inconel and other high Ni alloys, stainless steels, Cu and Cu alloys, Al, chemical Pb, mild steel, alloy steels and plain and alloy cast irons.

New Fatty Acid Process. U. S. Fractionation Method In Lancashire. *Chem. Age,* 62, pp 8-9, 12 (1950) Jan. 7. Plant shortly to be completed at Littleborough in Lancashire will distill fatty acids by fractionation method. Commercial quantities of the acids, of hitherto unobtainable purity, will be

obtained and are to be marketed under the trade name of Distec. Distillation unit is constructed entirely of stainless steel. Pumps are of stainless steel and are of many types, capable of pumping crude fats at 150 degrees F or fatty acids up to 500 degrees F. Crude fats and oils are split, at high pressure, in a battery of stainless steel autoclaves (stainless steel being over 1 in. thick).

Armour's Star. R. H. Potts and G. W. McBride. *Chem. Eng.*, **57**, No. 2, 124-127, Flowsheet 172-175 (1950) Feb. Armour & Co. has built a new plant at McCook, Ill. which will enable it to make a larger number of chemicals from fats, oils and fatty acids. Ni-Resist is used for the fatty acid pumps and ordinary steel for other stocks. The storage tanks for the fatty acids are stainless-clad steel. Monel-lined tanks are used for refining and bleaching of fat with H_2SO_4 and are used for the storage of H_2SO_4 and 50 percent NaOH. Acetic acid is stored in stainless steel tanks. The evaporator is stainless steel. Type 316 steel is used for the bubble plate still of the fractional distillator. In the nitrile conversion stainless steel is used for the reactor, converter, reflux condenser, vapor superheater, pitch column, and all connecting pipes and valves where fatty acids are present. Ni in the catalyst used in the conversion. Ni formate is the catalyst in the fat and fatty acid hydrogenation. Finished products of fatty acids are kept in Al tanks, and the amines and nitriles are in steel tanks.

A Staff-Industry Collaborative Report-Chemicals From Fats. R. L. Kenyon, in collab. with D. V. Stingly and H. P. Young. (Armour & Co.) *Ind. Eng. Chem.*, **42**, No. 2, 202-213 (1950) Feb. Type 316 stainless steel is used throughout the plant where there is contact with fatty acids. The exception to the rule is in the heater tubes where the temperature rises above 300 degrees C. Corrosion of Type 316 increases substantially as the temperature rises, whereas Inconel maintains its resistance. Table shows results of laboratory studies on corrosion effects of tall oil on Types 316, 317 and 302 stainless, Inconel and Hastelloy C. Reduced Ni formate catalyst is added to fats in the hydrogenation vessels, and the catalyst used for the conversion of nitriles to amines is Raney Ni. Fatty acids for processing are stored in Type 347 stainless clad steel tanks and carried in pipes of the same material. Finished product fatty acids are stored in Al tanks. Some of the pumps handling fatty acid materials are of Durimet 20 stainless steel. In preparing high melting acids, a Cr-plated rotating drum picks up a thin film of the acid which solidifies. 36 references.

Continuous Fat Splitting Plants Using the Colgate-Emery Process. H. L. Barnebey and A. C. Brown. Paper before the Amer. Oil Chem. Soc. Ann. Mtg., Chicago, Oct. 22, 1947. *J. of Amer. Oil Chem. Soc.*, **25**, No. 3, 95-99 (1948) Mar. In a discussion of the construction of a plant for the Colgate-Emery process for splitting fats, Inconel and Type 316 stainless steel are mentioned for the splitting column; C steel, stainless steel, and Al for fat storage tanks, stainless, Inconel or Al for settling and fatty acid storage tanks, stainless steel for pumps and for process piping in contact with fatty acids, Inconel or Type 316 stainless. Illustrations and flow sheet included. 7 references.

Corrosion Forum—Fatty Acids versus Construction Materials. Symposium on Fatty Acids vs. Construction Materials. *Chem. Eng.*, **56**, No. 4, 217, 218, 220; No. 5, 263, 264, 266; No. 6, 243-244; No. 7, 237-238, 240 (1949) Apr., May, June, July. Symposium includes: Glass-Lined Steel by S. W. McCann (Pfaudler Co.), Carbon and Graphite by W. W. Palmquist (Nat. Carbon Co.), Stainless Steel by G. L. Snair (Allegheny Ludlum), Rubber Lining by O. S. True (U. S. Rubber Co.), Porcelain by J. S. Chowning (Lapp Insulator Co.), Chlorimet by W. A. Luce (Duriron Co.), Iron and Steel by A. W. Spitz (Am. Cyanamid Co.), Worthite by W. E. Pratt (Worthington Pump), High Silicon Irons by W. A. Luce (Duriron Co.), Aluminum by E. D. Verink, Jr. (Aluminum Co. of America) Chemical Stoneware by F. E. Herstein (Gen. Ceramics & Steatite), Nickel and Nickel Alloys by W. Z. Friend (Inco), Durimet 20 by W. A. Luce (Duriron Co.), Protective Coatings for Fatty Acids by K. Tator, Protective Coatings for Fatty Acids by F. L. Sharpe.

Versatility in Fatty Acids. R. Williams, Jr. *Chem. Eng.* **56**, No. 7, 92-94; Flowsheet 128-132 (1949) July. New General Mills plant in Kanakee, Ill., combines hydrogenation and esterification units with hydrolysis equipment. Hydrolysis tower is lined with Inconel to minimize corrosion by fatty acids. Continuous evaporators are made of Cu for heat-transfer purposes since materials handled are not corrosive. Twitchell hydrolysis units are lined with Monel for corrosion resistance. Distillation trains are made of stainless steel. Reactor in hydrogena-

tion unit consists of a stainless steel tank which has steam coils and an agitator. In esterification unit, stainless steel kettles are used. To produce solid products there is a stainless steel single roll flaker.

High Temperature Processing of Fatty Oils and Acids. H. L. Barnebey. (Blaw-Knox Co.) Paper before Amer. Oil Chemists' Soc. Mtg., New York, Nov. 15-17, 1948. *J. Amer. Oil Chemists' Soc.*, **26**, No. 9, 493-502 (1949) Sept. For fatty acids at high temperature, stainless steel, especially Type 316, and Inconel, are suitable; for low temperatures, Al is satisfactory. For neutral glycerides, C steel can be used. Cu is now considered a poor material of construction because of its effect on the product, edible products are very sensitive to Cu, which affects the taste, odor, color and stability.

Commercial Manufacture of Lactic Acid. G. T. Peckham. Before Amer. Chem. Soc., Pittsburgh, Pa., Sept. 1943. *Chem. & Metall. Engineering*, **51**, No. 1, 185 (1944) Jan. *Chem. Eng. News*, **22**, No. 6, 440-443, 469 (1944) Mar. Lactic acid of any required purity is made by fermentation of starch hydrolyzates, molasses and whey. In some cases the substrate is refined; in others, calcium lactate is crystallized out as the primary refining step, while some processes employ solvent extraction. Crude acids are largely characterized by the starting substrates and methods of processing. Processing technique is described. Corrosion is one of the major problems confronting the technology of lactic acid manufacture, especially in the case of heat transfer surfaces. Iron and steel are of no use. Copper and copper alloys, including acid-resisting phosphor bronze, have a very limited life and introduce sizable quantities of copper which subsequently must be removed. Chrome steel has very poor resistance and most of the stainless steels and Monel metal are unsatisfactory. Certain stainless steels, particularly those containing Mo show reasonable resistance. Inconel and pure nickel are somewhat resistant but are still seriously attacked. Some of the relatively low iron alloys containing large percentages of Ni and Cr resist fairly well. Silver and tantalum are both very well suited for the operations except for their cost and relative unavailability. Most non-metallic materials are also quite unsuitable. On the whole, the handling of lactic acid presents a great many technical problems which to date have not been satisfactorily solved. The chemistry of lactic acid has not been at all well worked out, but a great deal of progress is now being made, largely through the efforts of the Eastern Regional Laboratory staff.

DISCUSSION

Comment by S. W. Shepard, American Cyanamid Co., New York 20, N. Y.:

In handling organic compounds of this general nature CO_2 is frequently present. Wherever water is below its dew point and oxygen is present carbonic acid corrosion may be severe on copper, etc.

Author's Reply:

I am pleased to have your comment with respect to the possible effects that carbon dioxide may have, particularly under conditions where the temperature is below the existing dew point of the system. It would seem that this source of possible corrosion of plant equipment should not be overlooked.

Comment by L. M. Nieliwocki, Sabine River Works, E. I. DuPont de Nemours & Co., Orange, Texas:

In confirmation of Mr. Scheil's remarks on the importance of composition in the corrosion resistance of Type 316 stainless steel to acetic acid, I would like to mention that severely corroded components at isolated locations in a Type 316 acetic acid recovery column were found to have deteriorated as a result of both chromium and molybdenum deficiencies. Uncorroded components in close proximity to the corroded parts were also analyzed and found to contain normal amounts of chromium and molybdenum.

Author's Reply:

Your comment with respect to difficulties associated with the handling of acetic acid using Type 316 stainless steel are of particular interest to me. I have been aware of the fact for some time that the composition of the chromium-nickel-molybdenum austenitic stainless steels is of considerable importance, particularly under conditions which approach a borderline application of this steel. It is my belief at the present time that under such circumstances the steel should have a chromium content toward the upper limit of the AISI range and I suspect that if at least 2½ percent molybdenum is present this quantity should be adequate provided the chromium content is high. In other words, a low chromium-low molybdenum austenitic stainless steel would be expected to show higher rates of corrosion in acetic acid recovery than would a higher chromium alloy with around 2½ percent molybdenum.

Remarks by Kenyon Stevenson, Jr., Rohm & Haas Co., Philadelphia, Pa.:

In laboratory tests of several mechanically and heat sensitized stainless steels (1000 degrees F for two hours) including Types 304 and 316, we found that fatty acids of the C-8 to C-18 range caused severe intergranular cracking. This, of course, is not necessarily reflected in calculated corrosion rates based on weight loss. Did your stainless specimens in formic acid and acetic acid service show this type of attack? If so would not this be of greater significance than ipy measurements?

Author's Reply:

In some instances we observed intergranular corrosion of the austenitic stainless steels in heat affected zones adjacent to welds in mixtures of acetic acid and formic acid. Of course, this type of corrosive attack is far more insidious than actual weight loss corrosion since the latter is predictable as far as expected service life is concerned to a far greater extent than intergranular corrosion is. Hence, we are in complete agreement that intergranular corrosion is of far greater significance than the inch penetration per year corrosion rate. For example, if the corrosion rate were low one would be obliged to think of possible intergranular attack but on the other hand if the corrosion rate were high one would not be inclined to use the steel anyway.

ERRATUM

Reproduced below is a corrected version of that portion of Page 13 of Bulletin III—Technical Practices, a part of the Report of the Correlating Committee on Cathodic Protection published in July, 1951 by the National Association of Corrosion Engineers, beginning with the first line of column 2 and continuing to the end of the first paragraph. Those who have copies of this report may wish to clip out the material below and paste it over the incorrect portion.

good electrical contact with the structure metal. A good contact is especially important because many erroneous or misleading voltmeter readings may occur if an IR drop or galvanic voltage is caused by any mill scale, corrosion products or pipe-coating that may remain between the contact prod and the bare structure metal. When prodding soft metals, due care must be taken not to puncture them.

Part I of Two Parts

Some Aspects of Ship Bottom Corrosion*

By PAUL FFIELD*

SHIP BOTTOM corrosion has harassed the marine industry ever since the introduction of iron and steel ships. Wooden ships sheathed with copper could be kept at sea for several years, but with the transition from wood to iron or steel frequent hogging was necessary to keep the bottom clean, and a planned schedule of docking and painting was required if corrosion was to be kept in check.[1]

Owners have learned to appreciate the need for continual vigilance in the proper maintenance of the bottom composition and, generally, corrosion of the underwater body is not a serious problem. The bottom composition and the schedule of docking are selected usually by experience, the owner following a combination best suited to his needs. The routine maintenance is intended to provide complete and continual protection but occasionally, due to some unforeseen circumstance, things may get out of hand and serious bottom corrosion may occur.

During the past several years there have been a number of cases of severe bottom corrosion with vessels built during and subsequent to the war. Figures 1 and 2 are typical examples. Such instances may be perplexing because apparently well-tried maintenance practices had suddenly become ineffectual. Owners, whose older vessels had been giving no trouble, all at once are faced with serious corrosion of the underwater body of some of their new ships.

Epidemics of corrosion of the underwater body seem to have occurred in cycles in the marine industry. This is important because, as Montgomerie[2] has pointed out, if the modern theories of corrosion are correct, they have always been correct, and except for some unusual conditions there should be no more corrosion in evidence today than in the past.

In tracing the cause of an epidemic of corrosion there is a natural tendency to concentrate on those contributing factors which have been subject to recent change, such as the effect of electric welding in promoting electrolysis, or perhaps the quality of the steel is suspected of having changed. There may even be the suspicion that the old-fashioned methods of steel making were best as far as corrosion resistance is concerned. While the fundamental cause of a corrosion epidemic may appear to be obscure, experience seems to show that bottom corrosion is due invariably to a combination of familiar circumstances. It is not surprising then that there are numerous references in the literature to cases of severe bottom

corrosion similar to those now being encountered on some ships.

Rate of Corrosion of Hull Steel and Significance of Pitting

Studies of the corrosion of steel in sea water bring out several significant points, the most important of which is that basically hull steel corrodes slowly— only at the rate of 0.003 to 0.006 inch per year. This is true, in fact, of just about any steel anywhere in the world (Table I). Unfortunately, the ship operator is not concerned with the average rate at which the steel wastes away over its exposed surface. He is concerned with the susceptibility to pitting and the rate of corrosion attack at these pits. If it were not for this pitting tendency, it would be hardly necessary to paint and protect the underwater body of a ship since something less than ⅛ inch of thickness is all that would be lost in twenty years. Such ideal conditions occasionally are encountered; steel

Figure 1—Typical corrosion of rivet points and plating around rivets on a new vessel, seven months after delivery.
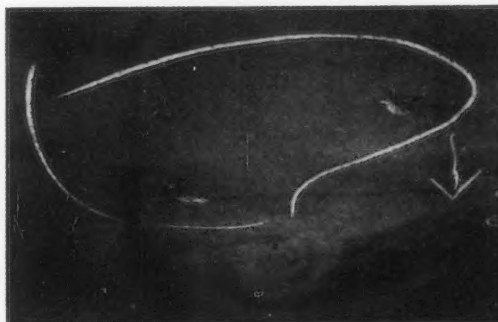
Figure 2—Typical severe pitting of bottom plating on a new vessel, ten months after delivery. These pits averaged ¼-inch in depth.

TABLE I
Rates of Corrosion of Carbon and Low Alloy Steel at Various Localities[1, 38]

LOCATION	Kind of Steel	Original Surface Conditions of Specimens	Duration of Test, Year	Rate, Inch per Year	Depth of Pitting, Inch
Sandy Hook, N. J.	Carbon	Pickled	2	0.0058	....
Bristol Channel, England	Carbon	Mill Scale	4	0.0042	0.009
Concarneau, France	Carbon	Pickled	1	0.0038	0.017
LeHavre, France	Carbon	Pickled	1	0.0042	0.031
Halifax, N. S.	Carbon	Pickled	15	0.0048	0.075
Aukland, N. Z.	Carbon	Pickled	15	0.0030	0.043
Plymouth, England	Carbon	Pickled	15	0.0024	0.065
Colombo, Ceylon	Carbon	Pickled	15	0.0036	....
Eastport, Maine	Carbon	Machined	3	0.005	....
Kill-van-Kull, N. J.	Carbon	Pickled	1	0.0041	....
San Francisco, Cal.	Carbon	Pickled	0.5	0.0066	....
Freeport, Texas	Carbon	Pickled	1	0.005	0.028
Kure Beach, N. C.	Carbon	Pickled	5.0	0.005	0.12
Kure Beach, N. C.	Carbon	Mill Scale	7.5	0.004	0.25
Gosport, England	Carbon	Sandblasted	1.2	0.0049	....
Gosport, England	Carbon	Sandblasted	1.2	0.0051	....
Gosport, England	Carbon	Mill Scale	0.5	0.0060	0.050
Kure Beach, N. C.	Carbon	Pickled	6.5	0.005	0.21
Eastport, Maine	Carbon		3.0	0.0046	Bad
Kure Beach, N. C.	Wrought Iron	Sandblasted	6.0	0.007	0.17
Kure Beach, N. C.	Ingot Iron	Sandblasted	6.0	0.007	0.19
Kure Beach, N. C.	3% Cr Steel	Pickled	6.5	0.002	0.035
Kure Beach, N. C.	5% Cr Steel	Pickled	6.5	0.003	0.091
Kure Beach, N. C.	2% Ni Steel	Mill Scale	7.5	0.005	0.094
Kure Beach, N. C.	0.3% Cu Steel	Pickled	6.5	0.005	0.21
Eastport, Maine	Cu Steel, 0.2% Cu		3	0.0045	Bad
Eastport, Maine	Ni Cu Steel, 2% Ni, 1% Cu		3	0.0042	Bad
Eastport, Maine	Ni Steel, 3.5% Ni		3	0.0036	Bad

piling on piers and bulkheads, for example, often will last under favorable conditions for twenty years or more without any protection. From the foregoing it is obvious that the problem in bottom corrosion is one of pitting and the causes of pitting deserve special attention.

Pitting is basically an electrochemical effect where conditions in the water or at the exposed surface of the metal encourage its solution at localized anodic (+) areas[3,4]. These anodic areas may show varying intensity and can be he result of relatively minor differences in chemistry, cold work, heat treatment, non-metallic inclusion, etc., all of which are characteristic of a heterogeneous material. Pitting is a natural tendency of steel and reference to Table I will show that the rate of attack at the pits is five to ten times greater than the general corrosion attack over he exposed surface.

The problem of controlling corrosion of the under-water body resolves into one of preventing the occurrence of pitting. This usually can be accomplished when regular bottom painting maintains a continuous paint film sufficiently impervious to prevent the access of sea water to the steel. Paints generally are not completely impervious to sea water under a hydrostatic head, but even if water does seep through, serious trouble will not occur if the pitting tendencies of the steel are mild. Of real concern to the operators and shipbuilders are those more vigorous causes of pitting; for example, any physical condition which may break down the paint and expose the steel, or an electrochemical effect so powerful that the paint film is insufficient to hold it in check. Either condition can result in virulent corrosion.

Pitting Corrosion Due to Velocity

One of the more vigorous forms of bottmo corrosion due to pitting is that which occurs at turbu-
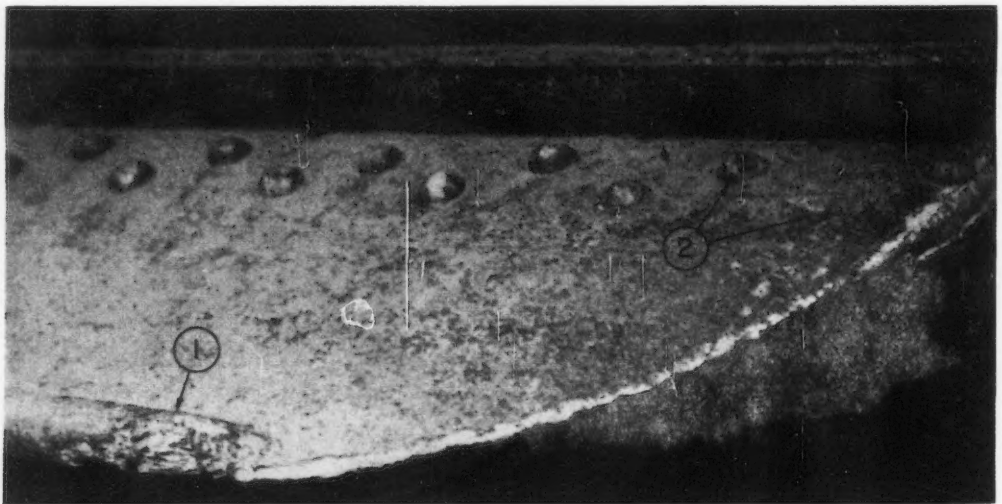
Figure 3—Corrosion activity due to water velocity at forward edge of a bilge keel. Note how the half-round (arrow 1) has been attacked and that some rivet heads (arrow 2) have corroded severely. Ship in service about three years.

Depth of Pitting, Inch
0.009
0.017
0.031
0.075
0.043
0.065
....
....
....
0.028
0.12
0.25
....
0.050
0.21
Bad
0.17
0.19
0.035
0.091
0.094
0.21
Bad
Bad
Bad

lent areas. The effect of this variable flow condition on bare metal is to create anodic (+) areas in regions of high velocity where the metal ion concentration is low and cathodic (—) areas in the zones of lower velocity where the concentration of ions is uninhibited. There will be a flow of electric current from the anodic areas creating a corrosion pit as the metal is lost by electrolysis at the anode.

Typical examples of corrosion due to velocity are shown in Figure 3 at the forward edge of a bilge keel, and in Figure 4 at the edge of a riveted lap facing forward. These are both well-known examples, and they are not often of serious concern to the operator because they do not affect the strength or the integrity of the vessel.

Any turbulent flow condition which results in a loss of paint protection locally is potentially dangerous because there may be other conditions present which might stimulate the flow of current from the anodic areas to increase the rate of attack still further. An example is the corrosion resulting from turbulent flow in way of the propeller, Figure 5. In this region galvanic currents flowing from the steel to the bronze propeller will be concentrated in those areas devoid of paint and will be added to the currents stimulated by variations in velocity or turbulent flow.

Sometimes the flow of electric current from the areas of high turbulence may be stimulated by conditions which are rarely suspected. For example, pigments are often added to paint in order to confer special benefits on the steel underneath. They may chemically treat the sea water seeping through the paint film so as to make the steel passive. Where there is no paint, such benefits will not accrue and this area will be active, creating a cell consisting of a small active area surrounded by a large passive area.[5] This situation is discouraging because what appears to be a good paint may not always be the best for the underwater body of a ship.

From the foregoing it is apparent that turbulence resulting from the minor roughness of the surface of the underwater body may be more or less harmless and result in only minor local corrosion. However, the presence of this local corrosion is always a danger signal and it is well to guard against it because other conditions may aggravate the attack. Welds should be well made and without unnecessary reinforcement.

Figure 4—Corrosion (arrows) at forward edge of a riveted lap on a ship in service nine months.
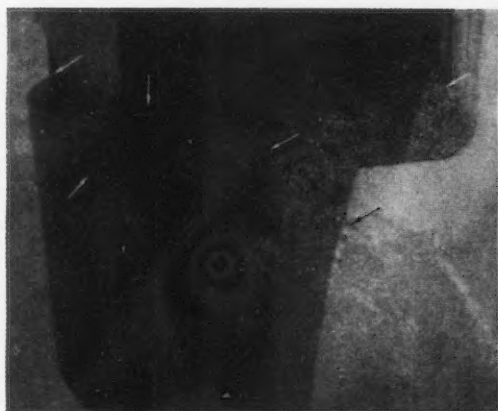
Figure 5—Typical corrosion at forward edge of rudder in wake of propeller, only three months in service. Corrosion is probably due to a combination of turbulence and galvanic currents flowing to the manganese bronze propeller.
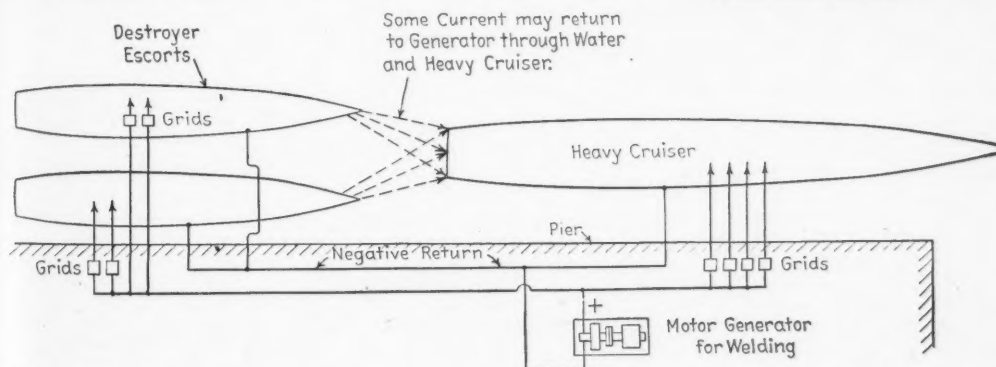
Figure 6—Welding wiring diagram of two destroyer escorts and one heavy cruiser outfitting at the same time. Note that when welding on the escorts current may leak to the cruiser and follow the cruiser negative return to the generator.
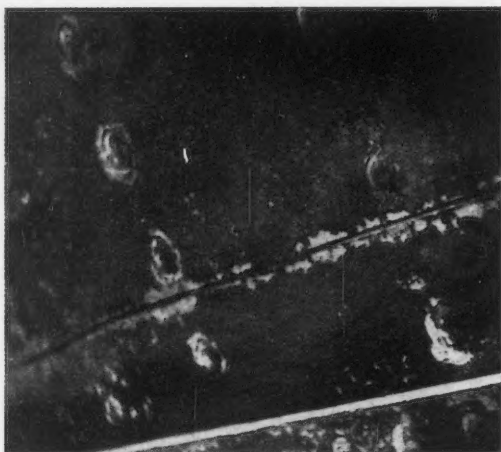
Figure 7—The paint on the plating of this vessel was scratched when fore poppets were removed after launching. Stray welding currents were focused on the bare steel, which resulted in severe localized corrosion in excess of ⅛-inch deep.

In this connection, submerged arc welds and those manual welds made in the downhand position should be less susceptible to velocity corrosion because generally they are smoother.

Weld ripples and rivet points complicate the painting problem because the paint tends to flow away from the high spots, and care should be taken to obtain good paint coverage. While some may advocate so-called anti-galvanic paints for this, in the author's opinion their only merit would be that they would help to build up the total paint film thickness in way of the weld.

Pitting Corrosion Due to Stray Currents

Electric currents generated on shore and led onto a ship which is afloat are a potenital source of stray current corrosion. There is always the hazard that they may stray from the ground return leads and reach the shore through the water by way of the underwater body. Loss of metal due to electrolysis will occur wherever this electric current leaves the ship.
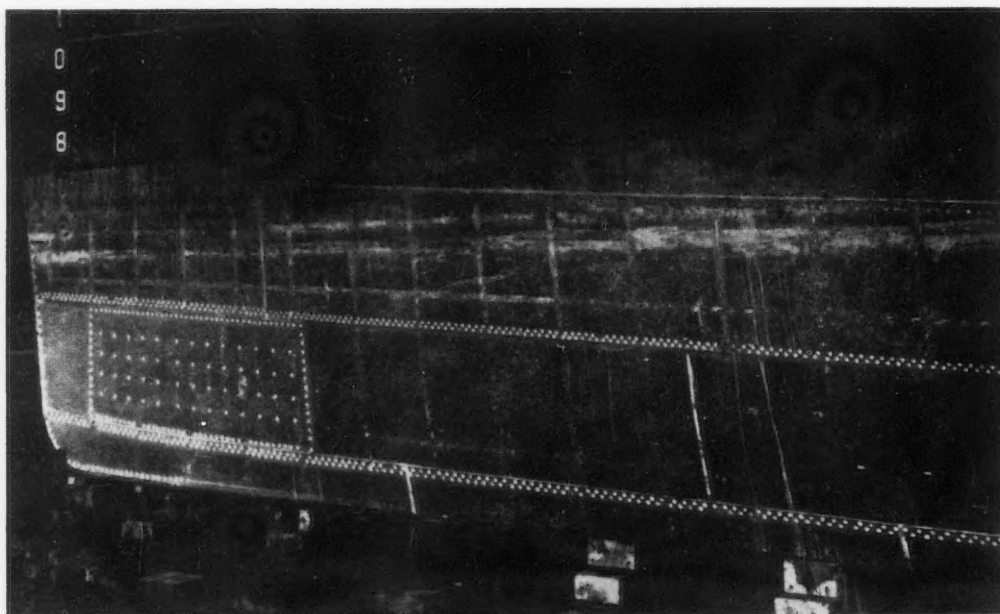
Figure 8—Example of white salt deposits, resulting from stray welding currents, on the underwater hull when a vessel was the cathode in the welding circuit. Note how deposits are concentrated on rivet points and in way of welding on the inboard surface of the shell, where the heat effect has caused the paint to deteriorate.
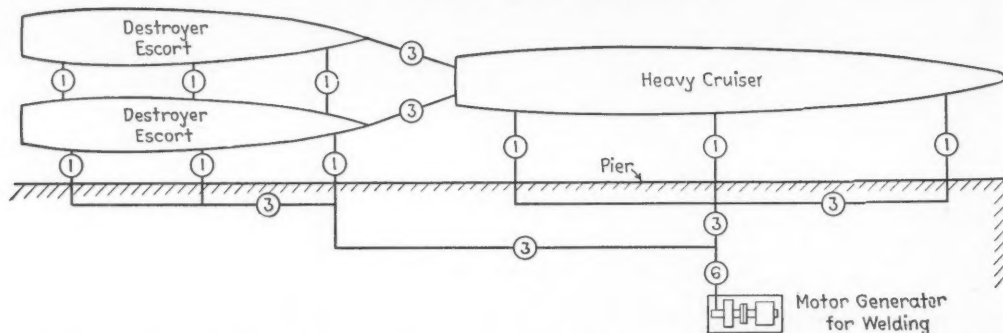
Figure 9—Showing increased capacity of negative returns to generator and bonding between ships. Circled numbers indicate size of cable in circular mils. Compare with diagram shown in Figure 6.

According to Faraday's laws of electrolysis, one ampere will remove about 20 pounds of iron in a year.

It is most unlikely that stray current corrosion can occur when the electric currents are generated on a ship when it is at sea. Even with a single-wire system there should be virtually no tendency for the current to leave the ship's steel hull because it is of much lower electrical resistance than the sea water.[6]

Welding during outfitting has been the usual source of intense stray current corrosion because the amperage is generally considerable—5000 amperes or more may be leaving the ship—and in the past the welding was invariably direct-current reversed polarity (ship as the anode in the welding circuit). With alternating-current welding, corrosion would be very much less because the ship would be the anode only half the time. With direct-current straight polarity (ship as the cathode in the welding circuit), there would be no corrosion—in fact, this is essentially the method of cathodically protecting metal suggested by Sir Humphry Davy 125 years ago.[7]

Figure 6 shows schematically how stray current corrosion can occur with electric welding currents when the vessel is in the fitting-out basin unless care is taken in planning the electrical hook-up. Since the vessel is painted, and paint has some insulating value, the electric currents will leave the ship at bare areas or where the paint is thin; e.g., where the paint has been scratched off when removing launching poppets, or under shores, cribbing, etc. If the total of these areas is small, the concentration of the attack will be extremely severe even if the total wastage of metal due to the electrolysis is not very great. The scratch in Figure 7, for example, had corroded to a depth of better than 1/8 inch in a short outfitting period.

An important point to appreciate in corrosion involving a flow of current from an anode to a cathode in sea water is that this electrolysis will break down the sea water into its component parts of hydrogen and oxygen, and a residue of sea salts consisting principally of calcium carbonate and magnesium hydroxide are deposited on the cathode.

An interesting example of this occurred several years ago at the Boston Naval Shipyard.[8] In this case the welding circuit permitted the currents to flow to the ship; i.e., the ship was the cathode, with the result that residual salts were deposited over much of the vessel, Figure 8. This illustrates in a graphic manner the areas where the paint film will break down first. Note how deposits are concentrated on rivet points, areas affected by the heat of welding on the inboard side of the shell, and at the outfitting waterline. In these areas the paint was severely blistered. In the case of the corroded plating in Figure 7, some point on the shore was acting as the cathode and the deposits would have been underwater on steel piling, etc., where eventually they would dissolve in the water and remain unnoticed. These sea salt deposits form a valuable telltale in the event of vigorous corrosion. If they can be located, it enables the investigator to find the cathodic area stimulating the corrosion at an anode.

Stray current corrosion, if due to leakage in the welding circuit, will be detected generally at the pre-delivery drydocking and of course it is not accompanied by any telltale white salt deposits on the vessel—these would be at the outfitting berth.

The most obvious method for preventing stray current corrosion is to place the welding generators on the ship. A second scheme is to make sure that there is a path of low electrical resistance in the welding return leads so that there will be little tendency for the current to stray from its intended course. This is accomplished, Figure 9, by placing at least three returns on each ship and bonding adjacent ships. It is important to see that the welding returns are of ample capacity. It is also just as well to make each return from two or three separate wires, especially where there is a significant tide. The tidal movement of the ship may tend to loosen the bolted connection between the copper wire and steel ship; if one wire only is used, the use of that welding return would be lost. In tidal areas care must be taken to see that there is not too much slack in these ground lines permitting the line to droop in the water. In the event that the wire sags in the water, current could flow from the ship through the water to a break in the insulation of the wire and thence to shore.

Pitting Corrosion Due to Galvanic Currents

When two dissimilar metals are in electrical contact in an electrolyte such as sea water, an electric current will flow from the anodic metal to the cathodic metal through the electrolyte. Corrosion resulting from this battery effect is known as galvanic corrosion and is familiar to all shipbuilders and ship operators, one of the best known examples being the corrosion at the stern of the ship due to the proximity of the bronze propeller.

Basically, galvanic corrosion is caused by the potential gradient between two dissimilar metals; from experience we have learned to avoid selecting materials widely separated in the electromotive series familiar to all engineers. Some of these tables list materials in their order of potential differences in sea water and show if corrosion will occur and which metals will be attacked or protected when they are in electrical contact. There is a second consideration, however, in galvanic corrosion which is of greater significance; namely, the relative areas of the two metals involved. If the areas of the two metals exposed to an electrolyte are equal, then there will be a definite flow of current from the anode to the cathode, and the corrosion of the anodic material will be approximately double the normal corrosion rate of that material out of contact with more noble metal. If the area of the anode is greatly increased and the area of the cathode unchanged, then the current density at the anode will be greatly reduced, and for all practical purposes increased corrosion of the anode due to the galvanic effect will be reduced to an insignificant value. A typical example of this effective combination of areas is the use of bronze trim in a cast-steel main injection valve. There is an appreciable potential difference between the bronze and the steel but there is not enough area of the bronze to accelerate corrosion of the large area of anodic valve body. Conversely, it is well known that
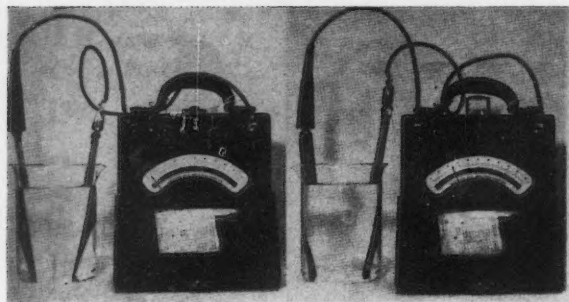
1. Bare steel to bare steel.   2. Bare steel to copper.

Figure 10—Millivoltmeter showing typical potential differences in sea water between: 1, bare steel and bare steel. 2, bare steel (left) and copper (right) 25 mv, and 3, bare steel (left) and steel covered with mill scale (right) 26 mv.
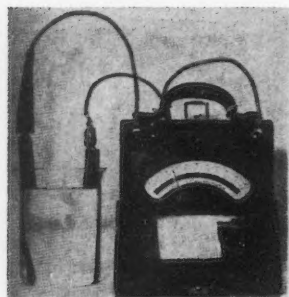
3. Bare steel to mill scale on steel.
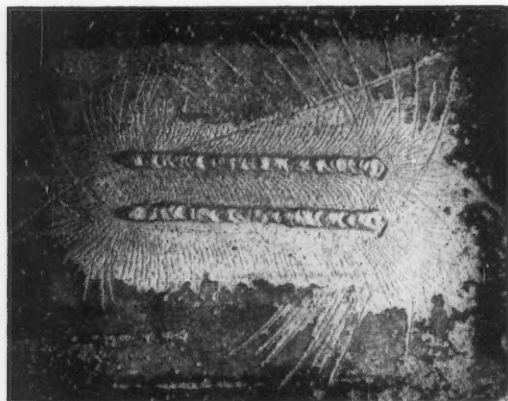
Figure 11—Shrinkage from the welding on this plate cracked the mill scale and exposed areas of bare steel. The plate was immersed in sea water for only 30 days. Concentrated corrosion to a depth of 1/32-inch has occurred in the breaks in the mill scale. Note how the corrosion has a slight tendency to undermine the mill scale at the cracks, etc.

it would be unsafe to put a steel seat in a bronze valve for salt-water service.

The point to appreciate when dealing with galvanic corrosion is that, when the areas of dissimilar materials are unfavorable, we must be continually on the alert for trouble even if the potential difference between the two materials is not great.

Telltale Characteristics of Galvanic Corrosion

Galvanic corrosion has a telltale characteristic which enables the investigator to identify it. As in the case of stray current corrosion, the flow of current through the sea water will cause white salt deposits to form on the cathode or protected pole of the gal-

vanic cell. Whenever these white deposits are observed, the investigator can be sure that galvanic corrosion is occurring, because they betray the cathode stimulating the corrosion. Another characteristic of galvanic corrosion which is important is that the evolution of hydrogen at the cathode as well as the alkaline nature of the cathodic products are likely to blister the paint. This blistering makes matters worse because it tends to increase the area of the cathode exposed to the salt water.

The control of galvanic corrosion involves avoiding dissimilar metals whenever possible and always avoiding relatively unfavorable areas.[3] In considering the effect of unfavorable areas the effect of paint must be taken into account. Favorable conditions are more likely to occur when the cathode is painted and the anode is left unpainted. While this is not always possible, there are occasions when conditions may be improved by leaving the paint off the material which is corroding and painting the material which is not corroding!

Galvanic Corrosion Due to Copper Sheathing on Steel Ships

Over the years there have been many instances of mysterious corrosion which upon investigation were traced to galvanic currents. The early steel shipbuilders faced this problem in the late 1850's and the early 1860's which marks the transition from wood to steel. Previously, with wooden ships they had been able to avoid marine fouling and shipworms by sheathing the wooden hull with copper which has inherent anti-fouling properties. This had been standard practice since 1765 when the British Royal Navy first tried the experiment of copper sheathing the bottom of H.M.S. *Alarm*.[1] With the introduction of iron and steel it was soon discovered that prolific marine fouling occurred, and attempts were made to sheath these iron ships with copper but dreadful galvanic corrosion was encountered. There immediately followed attempts to insulate the copper sheathing from the hull by means of rubber sheets[9] or sheathing the hull first with zinc, then with wood, and finally with copper.[10] The practical difficulty of maintaining this insulation or protection soon became apparent and copper sheathing of iron was abandoned in favor of copper-bearing anti-fouling paints.

Even in more recent times sporadic attempts have been made to sheath steel ships—with the same disastrous results. An interesting example occurred in 1907 in Ceylon when a new passenger vessel was copper sheathed to avoid the heavy tropical fouling in local waters. After the vessel had been in commission only a short while, the captain "noting her weird behavior wisely decided to beach her, whereupon the corroded hull literally fell apart at the waterline."[11] This case is particularly interesting because, as is often the case with accelerated corrosion, an attempt was made to hold the shipbuilder responsible for the trouble even though he had followed the owners' specifications.

Galvanic Corrosion Due to the Presence of Mill Scale

Of all the forms of galvanic corrosion, that due to

the presence of mill scale (cathode) on the surface of the steel (anode) is probably the most damaging. The reason for this is that the relative areas of anode and cathode are generally more unfavorable than with any other galvanic couple in marine service, with the possible exception of copper-sheathed steel ships. In spite of its devastating effect, galvanic corrosion due to mill scale is often not recognized as such, with the result that this form of corrosion frequently is shrouded in mystery.

Figure 10 illustrates the potential difference between mill scale and bare steel. It shows this to be of about the same order as that between bare steel and copper. An example of the combined effect of this potential difference and the unfavorable balance of relative areas referred to previously is illustrated in Figure 11. Two short welds were deposited on a 3-foot by 3-foot plate, well covered with mill scale. The shrinkage stress from this welding cracked the mill scale, exposing small areas of bare steel. The plate was exposed to sea water for only 30 days at the end of which time corrosion to a depth of 1/32 inch had occurred at the cracks in the scale! In another test, controlled percentages of mill scale were removed by sandblasting from several 12-inch square specimens before they were exposed to sea water. The depth of corrosion at these bare areas was directly proportional to the area of mill scale present as shown in Table II. In the light of these experiments one can only expect corrosion to occur on a vessel sheathed in mill scale similar to that which would occur if the vessel were sheathed with copper. If this is a valid observation, it raises a number of questions as to why corrosion attributable to the presence of mill scale does not occur more often. There are many factors to be considered, and the best approach is to review the literature, tracing the history of this form of virulent corrosion back to the period when it was first recognized.

Early Instances of Mill Scale Corrosion

It was probably in the late 1860's when the problem of galvanic corrosion due to mill scale on the underwater body of steel ships was first encountered. Wrought iron had been used in some ships prior to this period, but due to the particular nature of its oxides[12] it may not have been so prone to mill scale corrosion. The use of steel for hull construction was comparatively new and there was no real background of seagoing experience. Attempts to follow the wooden ship practice of copper sheathing to prevent

fouling had accentuated the galvanic corrosion hazard and reliance was being placed on anti-corrosive and anti-fouling bottom compositions.

If one reads between the lines, it appears that the virulent corrosion occurring in the early 1860's stemmed from mill scale even if it were not recognized as such. The Director General of Naval Architecture of the French Navy was quoted[13] as saying that, unless there was a composition developed to prevent rusting, the iron plated fleet of France must be renewed every five years. The British Navy had its troubles. Young[1] reports accelerated corrosion of H.M.S. *Grappler, Jackal, Antelope, Harpy, Bloodhound, Fairey, Myrmidon.* For example, *Jackal* foundered at Greenock because the plates were "eaten through unnoticed," *Bloodhound* required a new bottom, *Myrmidon* was "like a colander" and condemned. These troubles occurred in from one to five years after delivery. There is no mention of copper sheathing but there are references to red lead and other paints, and it seems probable in the light of subsequent knowledge that these accelerated corrosion rates might be traced to mill scale. King[14] expressed such an opinion in 1872 when he pointed to the scales (oxides) of iron as having a larger effect on the rusting of iron than other metals such as copper. King, in comparing the effect of mill scale to other metals, even refers to Pepys's *Memoires*[15] where the destructive effect of lead sheathing on rudder pintles is recorded, and makes the comparison that the oxides of a metal are electronegative and those of iron may be expected to cause increased corrosion.

By the late 1870's the British Admiralty was fully aware of the deleterious effects of mill scale, and it recognized that the only safe way to avoid trouble was to remove the cathodic material (mill scale) which was creating the galvanic couple. Since 1880 the hull steel of combat vessels in the Royal Navy has been pickled. It was at about this time that Farquharson[16] conducted corrosion tests for the Admiralty on the action of mill scale and found freedom from pitting when the scale was removed. When the scale was left intact, he reported that its effect in stimulating pitting corrosion was "considerable and continuous—equal in fact to a like area of copper."

This comparison with copper has been made frequently, notably by Newman in 1896,[17] by Cushman and Gardner in 1910,[18] and by Speller in 1935.[19] Speller was deeply impressed with the role of mill scale. He ascribed more localized corrosion in service due to this source than to any other combination of dissimilar metals! In fact, he developed a technique in tube rolling about forty years ago which would shell off the black oxide scale in the latter part of the rolling process, and was able to show the enhanced corrosion-resisting properties of tubes so treated.

Many investigators have studied these effects of mill scale on ship bottom corrosion. The paper by Lewes in 1887[20] is a classical example. So many of the discussers of his paper emphasized the effect of mill scale that Lewes stated, "I took it for granted that this question (of mill scale removal) had been finally settled many years ago. It was distinctly proved by Parker, Martell, Barnaby, and others that

TABLE II
Results of Corrosion Test Where Controlled Areas of Mill Scale Were Removed Prior to Exposure of the Specimen.

Specimen No.	Sandblasted Area, Percent of Total Area	Ratio of Cathodic Area to Anodic Area	Actual Corrosion Rate at Bared Areas, Penetration in Inch per Year
1	5	19:1	0.045
2	10	9:1	0.033
3	25	3:1	0.015
4	50	1:1	0.008
5	100	...	0.005

black mill scale was at the root of a great deal of the serious corrosion which took place on submerged iron surfaces and that it was absolutely essential that it should be entirely cleaned off before protective compositions could be put on with any chance of success."

Despite this background of experience and understanding of the mill scale corrosion phenomenon, troubles due to mill scale have persisted to the present time, stimulating periodic papers on the effects of mill scale such as Whipple,[12] who surveyed the galvanic effects, Pollitt,[21] who emphasized the difference between the galvanic effects of the various oxides of iron, and Hudson, who reported the classical work of the Marine Corrosion Committee of the British Iron and Steel Institute.[5] Several chapters of Hudson's book are devoted to the various aspects of the mill scale problem.

This history of mill scale corrosion might be summarized by stating that after their experiences with copper-sheathed steel ships in the 1860's, the engineers of that period had a sound understanding of what to expect from a cathodic material of relatively large area like mill scale on the bottom of a ship, and the role of mill scale was soon appreciated. The British Admiralty adopted pickling on their combat vessels and the leading naval architects and operators were stressing the need for mill scale removal. However, this understanding of the part played by mill scale in bottom corrosion on ships seems to go in cycles because over the years the industry has been plagued with epidemics of damaging corrosion which can be traced to this cause. It almost looks as though the role of mill scale must be periodically "discovered."

Mill Scale Corrosion Occurs in Cycles

It is not hard to understand why mill scale corro-

sion occurs in cycles when it is appreciated that there are only three ways to avoid it.

(1) The stimulating cathode (mill scale) must be removed altogether as by pickling or sandblasting.

(2) It must be reduced in area by weathering or other partial scale-removing methods (wire brushing, grinding, chipping, etc.) to the point where its cathodic influence can be tolerated.

(3) Painting must be relied on to prevent exposure of bare steel to the water or prevent the water from reaching the mill scale.

Pickling or sandblasting are positive and will avoid trouble.[2, 20] Weathering is variable and its efficacy is dependent on many factors. Painting, especially if there are large areas of mill scale, is precarious. Some owners and builders feel that the added expense of pickling is worth the insurance against trouble. Others rely on weathering and painting.

As long as weathering time and climate are effective in reducing the area of scale to safe limits, and as long as the paint is built up to an impervious thickness on the bottom, there will be no real trouble. This calls for a critical balance between three basic variables: storage and erection time of the steel, frequent dockings after delivery, and adequate paint maintenance. If the builder and operator maintain this balance over a period of years, there will be a tendency to assume that the absence of trouble is due to suitable quality of steel (good corrosion resistance), paint, and workmanship, whereas actually the weathering, docking, and painting have combined to keep in check an eruptive mill scale corrosion condition which is not affected by quality of material or workmanship.

As will be shown later, shorter building times, changes in steel making practice, and changes in paint
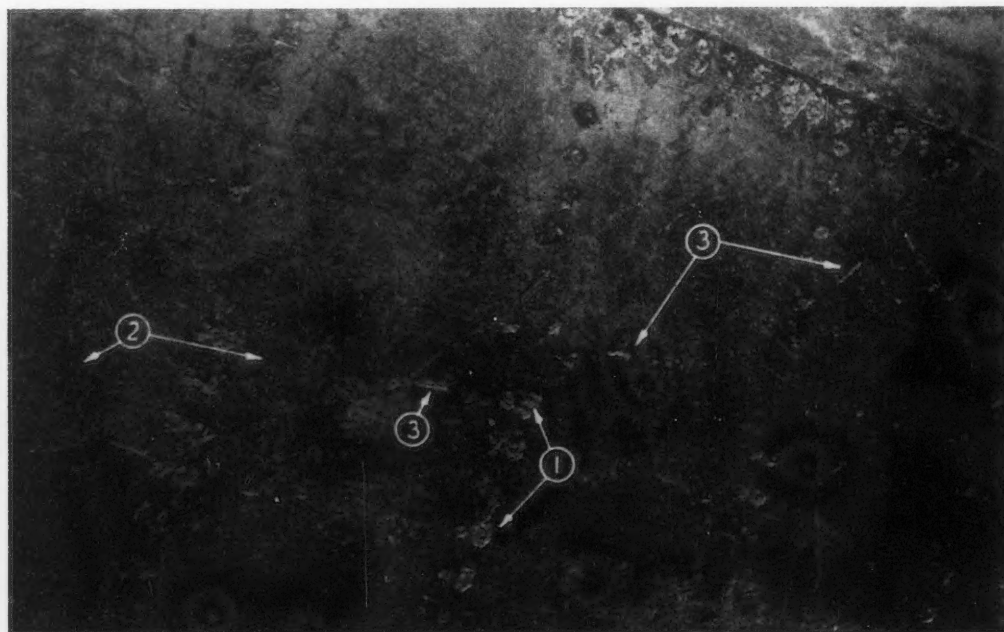
Figure 12—Mill scale corrosion on a vessel seven months after delivery. Note attack at rivet points and adjacent plating (arrows 1), white deposits of mill scale (arrows 2) and attack on bare steel (arrows 3).
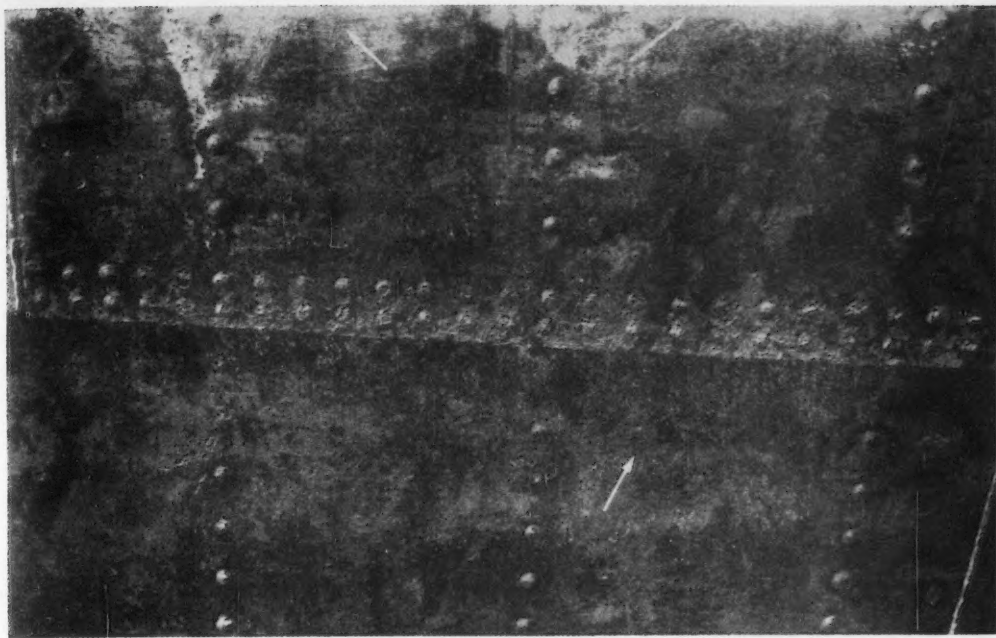
Figure 13—Mill scale corrosion of rivet points and adjacent plating on a new vessel after twelve months in service. Note white deposits (arrows).
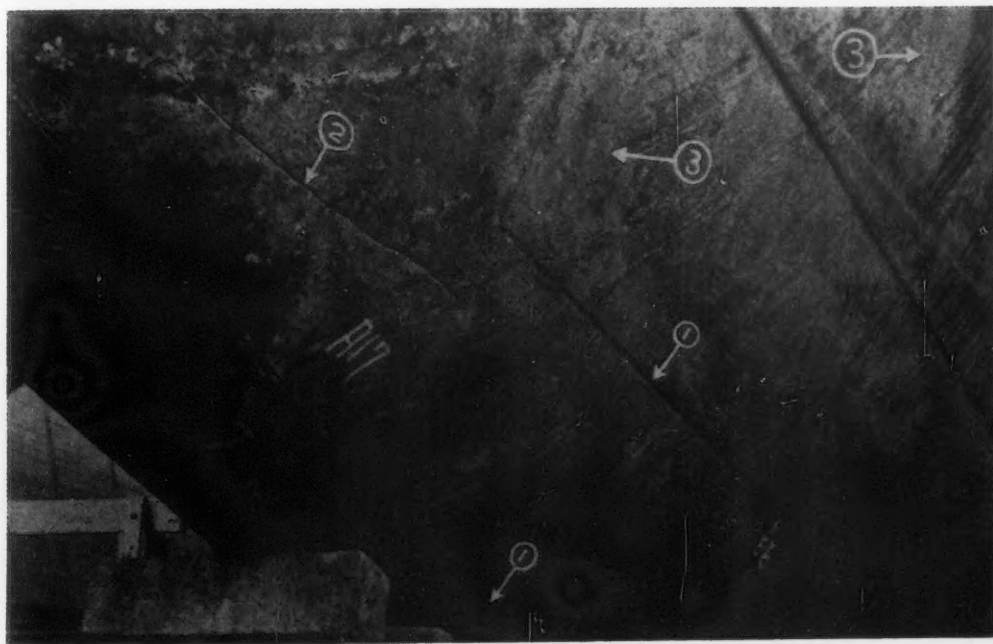
Figure 14—Typical example of weld metal corrosion (arrows 1) caused by mill scale on adjacent plating. Welds were corroded to below the level of the plates and about two thousand feet had to be built up. Note corrosion on plate (arrows 2) and white deposits (arrows 3). This vessel was built abroad and most of the shell plating was of British manufacture.

formulation can upset this balance and lead to an epidemic of corrosion.

Recent Examples of Mill Scale Corrosion

Periods of feverish shipbuilding activity are likely to result in a rash of mill scale corrosion problems, because insufficient time is available to complete the mill scale removal by weathering. Shipbuilders and operators may lose sight of the fact that painting and docking practices which were formerly adequate for good protection of the underwater body may have to be changed to take care of decreased weathering. It is not surprising then that numerous cases of this form of active corrosion have been encountered with vessels built during and subsequent to the last war. They can be attributed to two basic causes: the
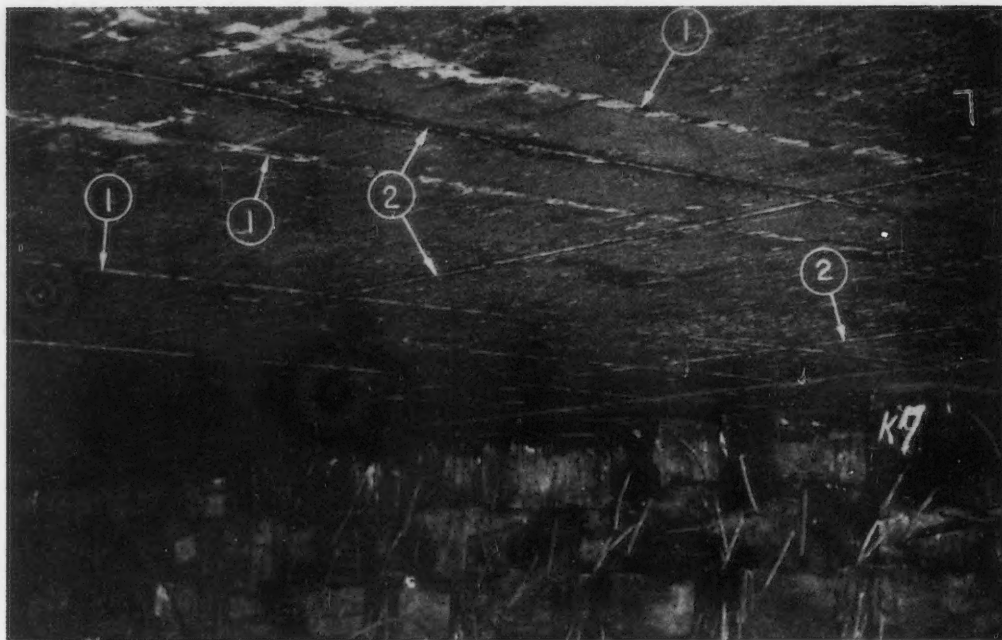
Figure 15—Extensive corrosion (arrows 1) on the bottom of the hull, opposite welds connecting floors to the plating. The heat effect caused the mill scale to crack off on the outside and has exposed bare steel to corrosive attack by mill scale remaining on the unheated areas. Severely corroded welded seams and butts are indicated by arrows (2).
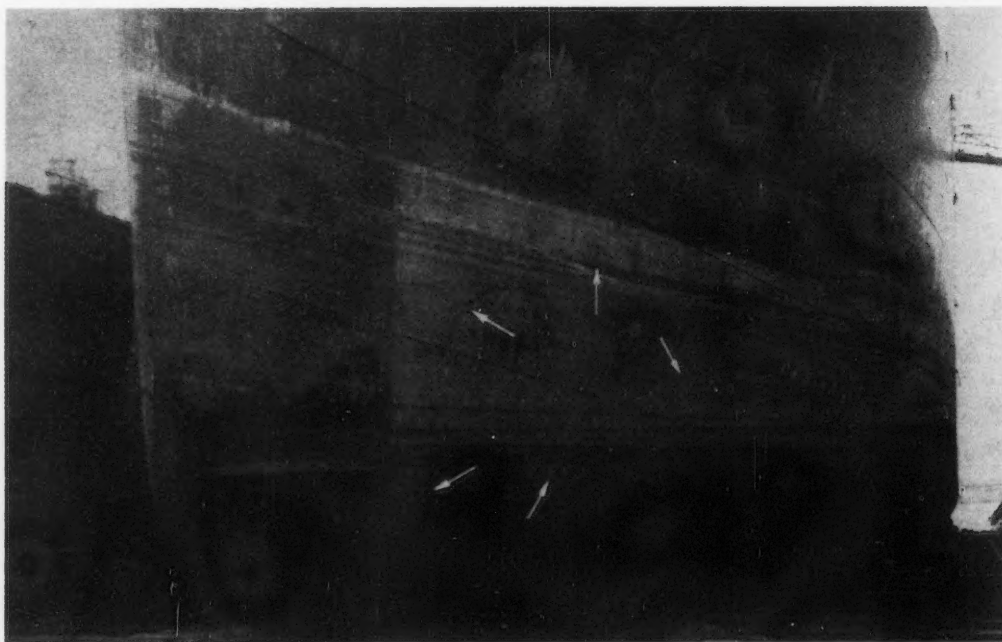
Figure 16—Extensive white deposits (arrows) denoting the presence of mill scale. Figures 1 and 12 are close-ups of the plating of this vessel on which 90,000 rivets were replaced.

speed-up in building associated with the war effort, and the decreased erection time due to the extended use of electric welding. These combined to give less time for weathering in the plate yard storage racks and on the building ways. Typical examples of this mill scale corrosion are shown in Figures 12 and 13 (riveted construction) and Figures 14 and 15 (welded construction).

These instances of corrosion are important and it might well be asked how they can be attributed to the underlying presence of mill scale with certainty. Mill scale corrosion has definite characteristics making its identification conclusive.

Characteristics of Mill Scale Corrosion on Ships

The most important characteristic of mill scale

corrosion is the presence of the telltale white deposits referred to in the paragraphs on galvanic corrosion as betraying the cathode stimulating the corrosion. Figure 16 is a good example of this and shows extensive white deposits over the underwater body of a vessel. These deposits delineate the mill scale which caused the corrosion shown in Figures 1 and 12.

Mill scale corrosion has other telltale characteristics which are noteworthy. Welds and rivet points may also be covered with a heat scale which, if unbroken, could protect them since, depending on its oxide nature, it may not be anodic to the mill scale on the plating. However, in the case of welds, slag is often trapped in pockets on the surface or in undercutting at the edge. The metal will be free from scale in these pockets, inviting attack by galvanic corrosion in the presence of mill scale on the plating. As soon as corrosion takes place, the pocket is enlarged and the slag can fall out, making the attack appear much worse than it really is, Figure 17.

Rivet points are also covered with a thin heat scale which may be ruptured at the close of the driving operation. Any discontinuities in this scale are open to galvanic attack stimulated by mill scale on the plating. In the case of flush rivets it is conventional practice to drive excess material to one edge and chip this off toward the end of the driving operation. This leaves a small crescent shaped area more or less free of heat scale and galvanic corrosion strikes here first, where it is likely to undermine the adhering scale and travel across the point as it increases its depth of penetration, Figure 18.

It is interesting to note that rivets and welds have
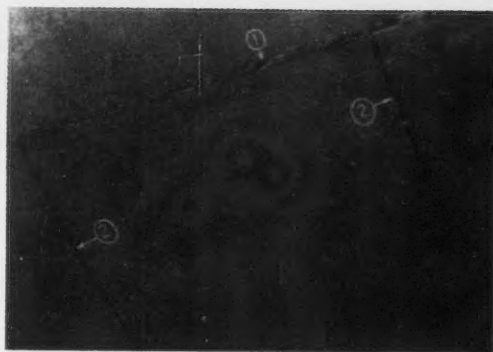
Figure 17—Mill Scale corrosion of welds. The attack on the seam (arrow 1) originated in slag pockets. Note the advanced stage of corrosion on the welded butts (arrows 2) of this vessel with only 12 months in service.

one other characteristic in common. During welding or when the rivet is being driven, mill scale on the plating in the immediate vicinity is sure to be ruptured, leaving the plating open to attack, Figure 12 [arrows (1)].

There are several other reasons why welds and rivet points are open to galvanic attack by mill scale. In both cases the exposed metal is under a severe state of stress which would help to cause breaks in the scale. Also the surface of the metal is uneven, consisting of a point or "hill" on the rivet, and "hills and valleys" in the ripples of the weld. This type of surface does not make for good paint protection, and these high spots on rivets and welds are probably the first points on a hull to be exposed to sea water attack, and as such become vulnerable if mill scale is
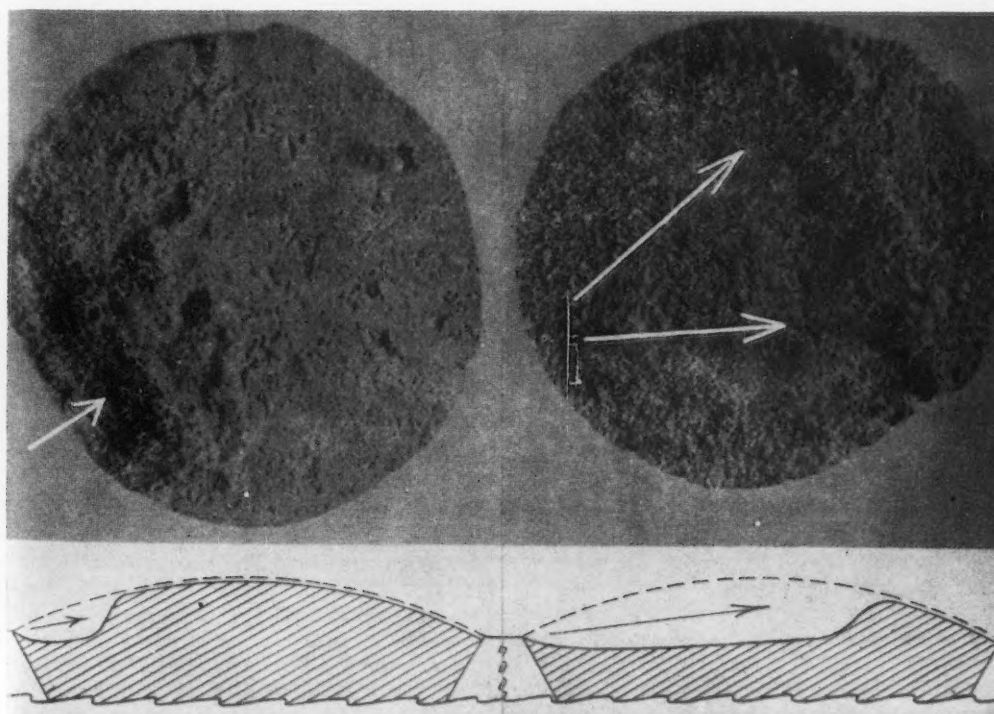
Figure 18—One edge of a flush rivet is likely to be free of heat scale after driving. Galvanic corrosion strikes here first (above, left) and travels across the rivet point as it increases in depth (above, right).
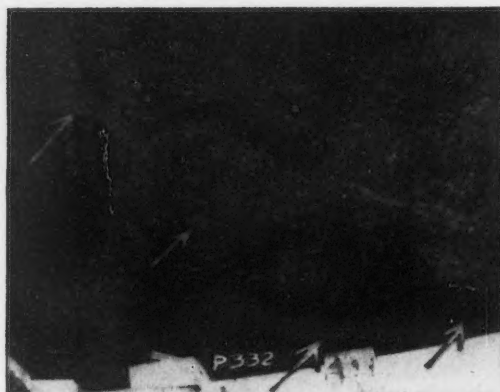
Figure 19—Mill scale corrosion on the bow plating of a tanker (ship A, Table IV), which occurred four years after delivery. Note that corrosion also occurred on the cast-steel stem. Several plates had to be renewed on this vessel.

present on the plating. This association of mill scale corrosion with rivets was pointed out by Pickworth[22] in discussing Bennett's[23] paper. He aptly remarked that mill scale should be included in any list of materials cathodic to steel and, furthermore, it would rank with lead and copper in the series. He then pointed to the susceptibility of rivets to mill scale attack.

Finally, mill scale corrosion will strike any form of bare steel in its vicinity. It shows no discrimination between plates, forgings, rivets, welds, and castings —all are likely to be attacked.

The main characteristics of mill scale corrosion can be summarized by stating that it strikes only where the steel is free from scale and paint. It concentrates at scratches on plates, on rivet points, and welds. It is accompanied by salt deposits. It should be noted that these salt deposits are not always as obvious as they are in Figure 16 because they may become stained with rust, when they assume the appearance of a conventional anti-corrosive or anti-fouling paint! This makes their detection difficult on occasion.

Factors Affecting Mill Scale Corrosion—Effect of Steel Quality and Shipbuilding Workmanship

It is not often appreciated that with mill scale corrosion the delinquent is the scale rather than the steel. When these cycles of corrosion occurred in the past, it was only natural that operators suspected deterioration in workmanship and in steel quality. The early steel shipbuilders and steel makers came in for their share of criticism. Matters were not helped when in 1843[24] several shipbuilders "stoutly denied that corrosion (and fouling) existed." Later the steel makers became the center of criticism and the quality of their product was suspected; for example, according to Lindsay,[25] chemists and engineers were in such a hurry to produce steel that they had overlooked the corrosion problem and done nothing about it. Even today the most frequent "explanation" for mill scale corrosion is either workmanship or material.

Epidemics of corrosion have focused attention frequently on the possible relationship between quality and sea water corrosion resistance. Diegel[6] investi-

gated this and concluded impure steel corroded no faster in sea water than its more refined counterpart. Later, in 1910, Cushman and Gardner[18] compared favorably steel of that period with steel made in former years. Lewis[26] made a similar comparison and went on to point out that the claim of better quality in the "old days" was not new—builders and operators had expressed this view ever since the introduction of steel to shipbuilding—he said it raised "disquieting ideas as to the corrodability of steel 100 years hence !"

The fact that welds, rivets, plating, castings, and forgings are often equally attacked on the same ship is strong evidence that quality or normal variations in analysis are not to blame for the corrosion. It is unlikely that steel in all these forms could be of inferior quality.

Accelerated corrosion occurred on some vessels built during and subsequent to World War I[25] and there was some agitation for the steel marker to improve the corrosion resistance of his product. Lithgow,[27] calling attention to the grave danger of panic action in changing the composition of steel, urged that shipbuilders, shipowners, and repair people direct their thoughts to greater care in preservation rather than criticizing the steel maker.

Lewis and other investigators of this same problem of deteriorating quality[26,27,28,29] came up with two important conclusions: first, that the quality of present-day steel was better and more consistent than the former product; and, second, there was a possible change in the make-up of the mill scale which could affect its removal by weathering as will be described later.

Removal of Mill Scale by Corrosive Effect of Sea Water

If the mill scale on the underwater plating is substantially intact at the time of prime painting before launching, it will constitute a hidden threat long after the ship is delivered. The corrosion shown in Figure 19 occurred on a vessel delivered in 1937 (Ship A, Table IV). The routine docking and paint maintenance were adequate and no trouble occurred for almost four years. But in 1940, following a change in route, it was docked but only after the paint protection had been allowed to deteriorate. The attack at both the bow and stern and in areas on the flat bottom was severe; a number of pits averaged 3/8 inch in depth by 6 inches across. Several plates had to be renewed. A hammer test confirmed the presence of large areas of mill scale under the remaining paint. This incident illustrates the need for removing the mill scale or at least reducing it to safe proportions prior to prime painting.

The galvanic effect of mill scale makes it apparent that in sea water the bare steel will be attacked and the mill scale will be protected. The only way then that galvanic corrosion can remove mill scale is by progressive undermining at the edges. This effect is shown in Figure 11. Numerous attempts to remove the mill scale by launching the vessel without bottom paint have been made, hoping that the sea water would corrode the mill scale. Johnstone suggested this in 1901.[30] A more recent attempt was made by the author on four destroyer escorts in 1944, but as
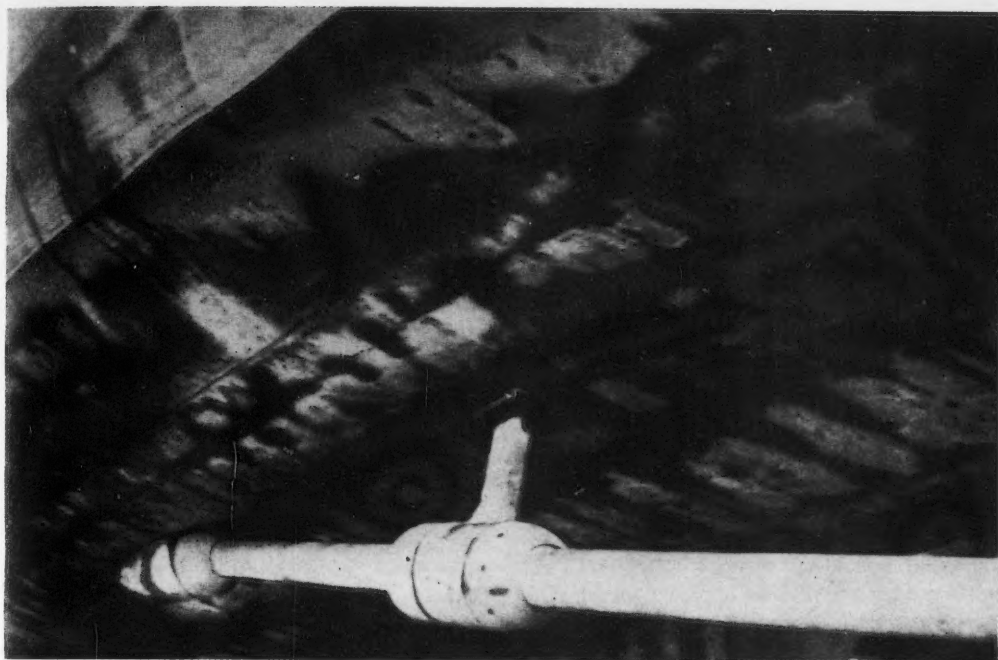
Figure 20—Extensive white scale deposits covering mill scale on a DE which was launched with the underwater hull unpainted. After 26 days outfitting no significant removal of mill scale had occurred.
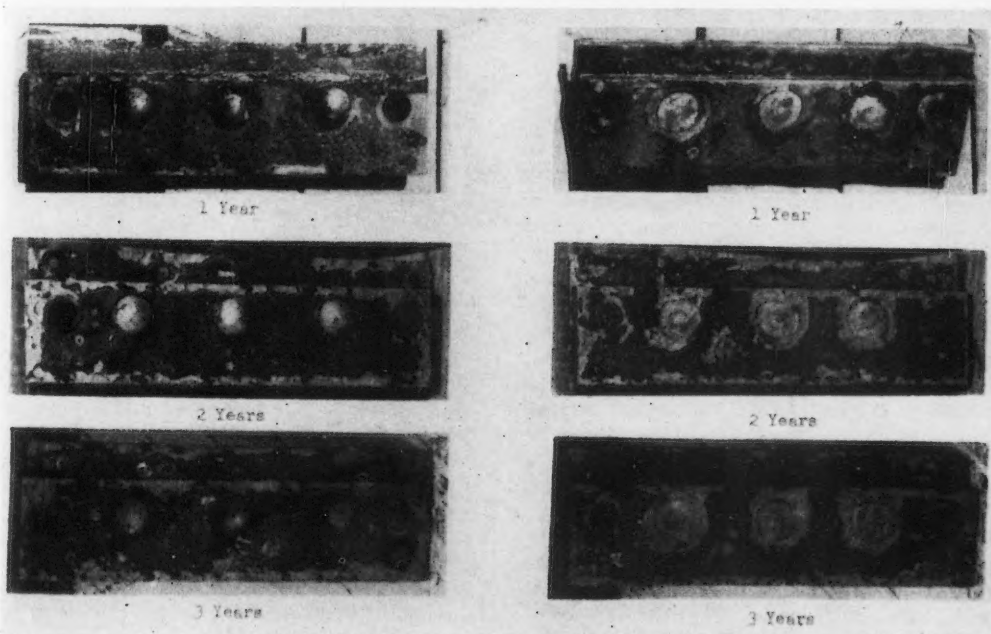
Rivet specimen No. 8. Point side. Exposed to salt water at Kure Beach, N. C. for periods of time shown.

Rivet specimen No. 8. Head side, exposed to salt water at Kure Beach, N. C. for periods of time shown.

Figure 21—Annual inspection photographs of corrosion rests of unpainted rivet specimens. These rivets were driven in plates well covered with miH scale. Note that after three years' immersion in salt water most of the mill scale is still intact.

shown in Figure 20 the mill scale was protected as evidenced by the extensive salt deposits on the cathodic areas. The fitting out period of these vessels was very short and there was not much time for corrosion at scale-free areas to progress to a dangerous degree. It had been hoped that some undermining of

the mill scale would have occurred at cracks and breaks. This was not the case, and as demonstrated in the following corrosion test it is unlikely to occur. In this test, unpainted riveted specimens with mill scale intact were exposed to sea water for three years. Examination at the end of one, two, and three years

showed that the contour and area of the mill scale was virtually unchanged and only minor amounts of scale had been removed by corrosion undermining it, Figure 21.

The most likely way that mill scale might be removed at sea is by the working of the vessel, which may crack the scale so that the slight undermining effect at the edges would be more effective. Or the working of the ship may be sufficient to shell off large areas of scale. In either event, if the scale comes off, it carries the bottom paint with it exposing bare steel which is then in danger from attack provoked by the remaining mill scale.

It can be concluded only that sea water corrosion or working stresses are at best unreliable methods for removing mill scale from the underwater body.

Removal of Mill Scale by Weathering

Substantial reductions in the area of residual mill scale can be effected by weathering, and there have been many investigations of this phenomenon. Apparently weathering is not entirely a corrosive action but one due as much as anything to expansion and contraction with variations in temperature. Weathering takes time and is dependent also on the type of the mill scale, not all plates responding in the same manner. Depending on locality and tenacity of the scale, complete descaling in the weather may require anywhere from one to five years.[5] However, in the author's experience in New England most of the mill scale will be removed in a year or two, especially on vertical surfaces.

Prior to the war, when building periods were longer, storage in the plate yard and erecting time on the ways were often sufficient to remove substantially all the mill scale. As building periods decreased and especially as the use of welding increased, the time for weathering became less and less, and ships were leaving the building yards with substantial areas of mill scale intact. It is not surprising that more and more instances of severe bottom corrosion developed.

While it has been established that quality has virtually no effect on the corrosion resistance of steel, the variations in the make-up of the mill scale itself are significant and important to the shipbuilder.[26, 28, 29] When hull steel is heated, it can combine with oxygen in three proportions—56 parts of iron to 24 of oxygen to form ferric or red oxide, Fe_2O_3; 56 to 21.3 for the black magnetic oxide, Fe_3O_4; and 56 to 16 for the black ferrous oxide, FeO. These oxides exist as three separate layers with the oxygen lean ferrous scale nearest the plate and the oxygen rich ferric scale nearest the atmosphere—the familiar red rust. This latter ferric oxide is the only stable oxide, and there is a tendency for the ferrous oxide to absorb oxygen from the air and revert to the ferric form. This is the chemical change which occurs during weathering. The change is accompanied by an increase in volume which encourages the layers to break away and fall clear of the plate.[26]

The oxide layers making up the surface scale do not always occur in the same proportion, and it has been shown that the rolling temperature is influential in determining the thickness for each oxide.[26, 31] High

rolling temperatures, in the order of 1800 degrees F, favor the formation of ferric (red) oxide but this diffuses in from the surface with the formation of the black magnetic oxide. If the rolling temperature is low, in the order of 1300 degrees F, very little diffusion inwards of the red oxide occurs. Consequently plates finished at a high temperature have a relatively thin surface layer of ferric oxide, because of diffusion, so thin in fact that it is transparent and the plate takes its color from the relatively thick black oxide immediately below. With low finishing temperatures, the relative thicknesses are reversed and the red oxide predominates on the surface to give a red effect.

The response to weathering depends on the relative thickness of these intermediate layers and it has been shown conclusively[26, 31, 32] that steel finished at high temperatures sheds its surface scale in weathering more quickly than steel finished at low temperatures. This in itself is significant, but of equal importance may be the conditions surrounding rolling. For example, hot plates instead of cooling individually and quickly may be stacked and cool more slowly under conditions favorable to the formation of extremely thin and tenacious layers of oxide. This was true for some of the plates rolled on strip mills. The important point is that rolling mill improvements as they were developed over the years have influenced the formation of mill scale. The weathering of plates today may well differ from that of thirty years ago. Weathering may also be affected by finishing temperatures or cooling practices. These viewpoints were summed up by Pearson[33] "shipbuilders will welcome the authoritative pronouncement that the epidemic of virulent corrosion affecting newly constructed vessels in recent years is due to the type of scale formed by modern high-speed rolling mills—an unfortunate accompaniment of progress."

While this matter of finishing temperature may explain why the mill scale survives the building period on some ships with disastrous results, it does not point to weathering as being a satisfactory solution to the scale removal problem. Weathering is at best only a help in removing mill scale and for complete immunity from mill scale corrosion the more positive processes of pickling or sandblasting are preferred. Sandblasting incidentally requires special precautions in painting to avoid blistering (see Appendix).

Role of Paint in Mill Scale Corrosion

If the mill scale is substantially intact, satisfactory performance of the hull steel is dependent on the owner maintaining an adequate paint film over the scale. It has been well established that mill scale forms a poor basis for paint[5] and it is often difficult to build up an impervious paint film over the scale in the early life of the vessel. Success in this respect depends almost entirely on the owner recognizing the liabilities involved and following a carefully planned schedule of frequent dockings at three and six-month intervals in the first year or two.[2, 5, 23, 34] While these frequent dockings have been established as good practice, not all owners follow this procedure and

longer periods sometimes elapse before the initial docking, often with damaging results.

There is some reason to believe that the old-fashioned paints had an advantage over their modern counterparts in stifling mill scale corrosion. While linseed oil paints have long been recognized[35] as not well suited to underwater protection, there are indications that these slow drying paints may adhere to mill scale better than the modern quick-dry priming paints. The performance of the modern paints also differs in many respects, particularly in regard to their life, and their adhesion to mill scale. This is shown in Table III which summarizes some of the author's tests now in progress at Duxbury, Mass.

Evans[36] pointed out that to get the benefit out of some inhibitive types of paints it is necessary that they be in direct contact with the steel. If mill scale prevents this, the paint may fail prematurely and corrosion on the steel can be intensified. In other words, a paint which may be very good over fully weathered or pickled plate may be definitely harmful over mill scale.

From the foregoing it will be seen that freedom from mill scale corrosion troubles will be dependent largely on the type of paint selected. This in itself might explain why some vessels are in more trouble than others.

With large modern tankers there is another angle which is important as far as the bottom composition is concerned. Because of their draft and the waters in which they operate, it is not unusual for them to scrape bottom. This generally results in the removal of some paint from the bottom, creating the essential conditions for vigorous corrosion if mill scale is present.

To summarize these sections on weathering and painting, it is not hard to see how unsuspected changes could occur in the characteristics of the paint, and the weathering tendencies of the steel, to the point where corrosion could get out of hand. In the author's opinion, this is the most likely explanation of the periodic outbreaks of mill scale corrosion.

Effect of Mill Scale on 24 Ships

The author has had the opportunity to follow the bottom corrosion performance of a number of vessels by making consecutive drydock inspections over periods up to several years. The results of some of these inspections are shown in Table IV. While corrosion was experienced in cases where the mill scale had been left intact, this corrosion was halted when the underwater body was sandblasted and there have been no cases of accelerated corrosion on the pickled or sandblasted vessels even when the paint was scraped off. While the author does not wish to state that mill scale is the only source of bottom corrosion, he is of the opinion that its role is far more influential than is generally suspected. He

TABLE III
Performance of Various AF Paint Systems in Sea Water Over Different Surface Preparations.

| Brand [5, 6] | TIME TO FAILURE IN MONTHS[1] | | | | | |
| | Over Conventional Wire-Brushed Scaled Surface | | Over Sandblasted Surface | | Over Partially Ground Surface[2] | |
	a[3]	b[4]	a	b	a	b
A.	2	3	2	3	2	3
B.	2	3	2	3	2	4
C.	3	5	2	3	4	12
D.	2	5	2	6	4	6
E.	3	5	4	6	5	7
F.	(good at 14)		(good at 14)		(good at 14)	
G.	(good at 14)		13	good at 14	(good at 14)	
H.	10	good at 14	2	9	(good at 14)	
J.	7	good at 14	7	11	3	good at 14
K.	11	good at 14	6	good at 14	(good at 14)	
L.	(good at 14)		12	good at 14	(good at 14)	

Notes:
[1] Divided into initial and total failure.
[2] All rust and loose scale and part of tight scale removed by resin bonded silicon carbide grinding such that about 50 percent bright steel was exposed.
[3] Initial signs of failure.
[4] Considered failed usually by blistering or peeling, etc.
[5] Paints A through G generally classified as conventional ship bottom paints.
[6] Paints H through L are vinyl systems.

TABLE IV
Records of Drydock Inspections on 24 Ships Showing Influence of Mill Scale.

| SHIP | Pickled or Sandblasted Before Delivery | MILL SCALE CORROSION | | | Sandblasted After Corrosion | Further Corrosion | REMARKS |
		Present	Degree	First Observed (Months)			
A.	No	Yes	Very bad	46	No	No record	Some bottom plates renewed
B.	No	Yes	Bad	6	No	No record	Some bottom plates renewed
C.	No	Yes	Very bad	6	No	Vessel sunk	Some bottom plates renewed
D.	No	Yes	Very bad	7	Yes	No	
E.	No	Yes	Moderate	3	No	No	
F.	No	Yes	Very bad	16	Yes	No	
G.	No	Yes	Minor	5	No	Yes—moderate	
H.	No	Yes	Moderate	4½	No	Yes—moderate	
I.	No	Yes	Bad	4½	Yes	No	
J.	No	Yes	Moderate	4	Yes	No	
K through X.	Yes	No	....	....	....	No	Superficial rusting at bare areas

Corrosion Rating:—**Superficial**—Slight rusting—no measurable attack.   **Minor**—Corrosion up to $\frac{1}{32}$ inch deep.   **Moderate**—Corrosion up to $\frac{1}{16}$ inch deep.   **Bad**—Corrosion up to $\frac{1}{8}$ inch deep.   **Very Bad**—Corrosion $\frac{1}{8}$ inch deep and up.

has been deeply impressed with the absence of accelerated corrosion at bare spots on ships free from mill scale. In no case to date has he observed anything more than superficial rusting on these ships, even on deep draft tankers when paint has been scraped off to bare metal. This is in direct contrast to the author's experience with other ships when similar conditions of grounding have invariably resulted in pronounced localized attack at the bare areas. Figure 19 is a typical example and leads one to suspect that when the mill scale is left on the hull it can even exert its influence through several coats of paint and cause accelerated corrosion where nothing but superficial rusting would have otherwise occurred.

Effect of Mill Scale in Repairs

Up to this point only mill scale corrosion on new ships has been considered. In some respects old vessels undergoing bottom repairs are even more vulnerable. This is because the owner is likely to lose sight of the fact that the few new plates in the bottom must be treated as a new ship would be treated. He might be prepared to dock a new ship in three months and six months, but it might never occur to him to follow the same procedure after repairs to an old vessel. Figure 22 is a typical example of mill scale corrosion on a repaired vessel. This vessel was about 20 years old when a number of plates were renewed in the underwater body. The vessel was not docked until a year had elapsed after repairs. It will be noted that the corrosion is concentrated around rivets, welds, and calked seams. This seems to point to workmanship and material, but actually these are the points most likely to be devoid of mill scale and where the paint will break down first, leaving them open to attack stimulated by the surrounding mill scale.

To guard against mill scale corrosion in repairs involving the renewal of underwater plating, ample time must be allowed for adequate bottom painting. If the mill scale is not removed, special consideration must be given to the selection of the paint (Table III, paints F and G). It is also advisable to arrange a schedule of "new ship" dockings in the first year of operation after the work is completed. The best insurance, however, is to remove the mill scale from the new plates.

Galvanic Corrosion Due to Copper-Bearing Paint

One cannot overlook the possibility of the copper in anti-fouling paint creating conditions ideal for galvanic corrosion. This has been studied by a number of investigators, and it has been demonstrated that some galvanic effect is created at scratches or bare areas, the copper in the paint acting as the cathode and the bare steel as the anode. Redfield[37] has shown that the degree of this galvanic attack varies directly with the amount of copper flake or copper oxide in the anti-fouling paint and inversely with the number of undercoats. The greater the amount of copper in the paint the worse will be its cathodic effect. Paint beneath the anti-fouling composition insulates the copper from the steel hull and the better this in-

sulating effect, the less will be the galvanic corrosion. This has been known for many years, and most marine paint systems consist of a priming coat applied to the steel, followed by several coats of anti-corrosive paint, the prime function of which is to build up an insulating film of adequate proportions beneath the copper-bearing anti-fouling paint. The composition of these anti-corrosive paints is such that generally they do not have any particular anti-corrosive characteristics in themselves but they are effective in keeping the copper-bearing paints separated from the steel underneath.

The author's experience, previously referred to, of the deep draft tankers which had grounded and exposed the underwater body plating to the sea water without dire results seems to suggest that the galvanic effect between the copper-bearing anti-fouling paint and the bare hull is not very significant, and that the anti-corrosive paint is fulfilling its function of preventing the flow of current from the steel to the copper pigments.

Cathodic Protection

It has been shown that the electrochemical effect in corrosion consists of solution of the metal at the anode and protection at the cathode. This cathodic protection is of interest to shipbuilders and operators, and it is often utilized where local attack might otherwise be severe. It was Sir Humphry Davy who first suggested protecting the underwater body by making it the cathode in a galvanic cell, and the use of zinc for this purpose has persisted for the past 125 years.[7] The theory behind the application of zincs is sound but experience seems to question whether zincs are as effective as is generally supposed.

Zincs have been omitted from some ships without dire results. For example, three sister vessels built at Quincy before the war had no zincs or other means of protection in way of the bronze propeller and no undue corrosion was experienced. One of these vessels was taken over by the U. S. Navy during the war and conventional zincs were installed. Examination of all three vessels after the war revealed no difference between the two ships without zincs and the third ship with zinc protection.

Many owners have replaced zincs with slabs of a very low carbon iron, such as Norway or Swedish iron, in the belief that it was anodic to the higher carbon hull plating. While the potential difference between these two materials would not be very great, all indications are that, if anything, hull steel is anodic to Swedish iron. However, the fact that these slabs of iron do corrode actively when placed in way of the propeller aperture is significant and it perhaps points to one of the prime functions of bare zinc or bare iron in the vicinity of the propeller.

If we assume that a manganese bronze propeller is the cathode with the hull as the anode, the degree of accelerated corrosion of the hull will be dependent on the relative areas between the bronze propeller and the sum of the bare spots in the paint on the plating, stern castings, and rudder. If these bare spots are collectively small in area, the rate of attack will be extremely high. If the area is large, it will be

proportionately less. Bare zincs or iron increase this total area of bare anodic metal exposed to the bronze propeller and consequently the depth of corrosion at holidays in the paint on the after-body will be proportionately reduced. Zinc or iron may offer cathodic protection in some degree but this can well be secondary to their material advantage in increasing the total area of anode (area of zincs plus holidays in the paint) exposed to the propeller. Frankly, the author would fully expect slabs of ordinary hull steel to do just about as much good as the equivalent area of zincs or Scandinavian iron. These Scandinavian irons seem to have no special virtue as far as galvanic effect is concerned, and even the efficacy of zinc in this respect is open to suspicion.[38]

Recent research regarding the electrical potential between zinc and steel points to it being variable. It is suspected, for example, that the potential varies with the purity of the zinc, with the water velocity, with the water temperature, and with time. Not only can the potential difference between zinc and steel vary, but it can even change its polarity to the point where it will become cathodic to steel. It is conceivable that in the turbulent water in way of the propeller, zincs could change their potential in this manner, becoming cathodic to steel, and they would then cease to offer cathodic protection. This deleterious galvanic effect would be negligible, of course, because of the relatively small area of zinc as compared to the underwater body of the ship. Zincs would, of course, still function in a beneficial way due to their increasing the anodic area coupled to the cathodic bronze propeller.

The preceding paragraph indicates that either zinc or pure iron may be of little value as a means of cathodically protecting the ship's hull but more positive cathodic protection could be obtained possibly if magnesium anodes were substituted for this purpose. Recent research has shown that protection afforded by magnesium is more positive and more far-reaching than that offered by zinc. A small magnesium anode attached to the center of a 12-foot square plate offered complete protection all the way out to the edge of this plate until the magnesium had wasted away completely. This plate was exposed unpainted at Kure Beach, N. C., where the temperature of the ocean is between 70 degrees and 80 degrees F.[39]

Magnesium anodes have been used with considerable success in protecting piling, and off-shore drilling rigs used by the oil industry. When the anodes have been placed at strategic locations, almost complete protection of the underwater surfaces of the steel structure has resulted.[40] While these instances do not involve any significant water flow or velocity, they do point the way to magnesium anodes as a means of protecting ships bottoms. The scheme is now being used with some success in the laid up fleet[41] and trial installations have been made on three seagoing vessels of the Royal Canadian Navy with encouraging results.[42]

This experience with magnesium anodes strongly suggests their use as a substitute for zinc or Scandinavian iron in the vicinity of manganese bronze
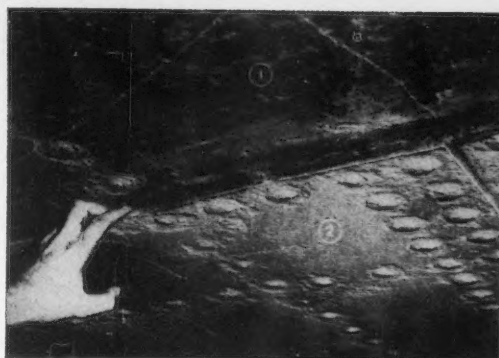

Figure 22—Accelerated corrosion of rivet points and plating. Vessel was twenty years old but a number of plates had been renewed about twelve months previously. The upper plate (1) is the original hull and the lower (2) is the new plate. Note attack on both plates caused by mill scale on the new plates.

propellers. Tankers and other vessels that are likely to operate in shallow water will be particularly susceptible to corrosion pitting due to velocity attack because of the abnormal aeration of the water and the presence of sand, silt, etc. In the areas subject to this attack, some degree of cathodic protection possibly might be afforded by magnesium anodes.

There are several legacies of cathodic protection which are of real interest to the ship operator. Probably the most important of these is the deposition on the cathode of salt deposits. The film thickness, hardness, and solubility of these plated out deposits can be controlled by controlling the current density. When these deposits are continuous and relatively insoluble, they will afford complete protection of the steel underneath as long as they remain intact. This method of protection has been exploited commercially for several years.[43]

One of the difficulties encountered with cathodic protection is that the evolution of hydrogen and the alkalinity at the cathode both tend to blister the paint and it is exceedingly difficult to obtain good adhesion of almost any kind of paint on a cathodic surface.

Summary

In the author's opinion the aspects of bottom corrosion of interest to the operator and shipbuilder can be summarized as follows:

Normally, hull steel corrodes slowly in sea water. It wastes away at a rate of less than 0.006 inch per year, which is equivalent to about $\frac{1}{8}$ inch in twenty years. However, the problem facing the shipbuilder and operator is not one of general wasting away but rather one of localized pitting at higher rates of corrosion. Pitting is basically an electrochemical effect, the loss of metal occurring whenever electric currents flow from the metal to the sea water. Hull steel, due to its heterogeneous nature, has an inherent tendency toward pitting, which generally can be tolerated. However, extraneous conditions may stimulate the flow of electric currents from the hull plating and cause extremely destructive pitting. The two most vigorous forms of hull corrosion due to pitting stem either from stray electric

currents returning to a shore source or from galvanic currents. Especially destructive are those galvanic currents flowing from bare steel to mill scale.

Stray current corrosion is due usually to stray welding currents during outfitting and as such is essentially a problem of the shipbuilder. They can be controlled by placing the generators on the ship or with adequate ground returns from the ship to shore. It is extremely unlikely that electric currents generated within the ship when the vessel is at sea would cause any corrosion on the outside of the underwater body, because there would be no inducement for the currents to stray from the hull plating.

Our industry has had to contend with mill scale corrosion for the last eighty years or more and with this background of experience it is surprising that we still encounter serious trouble from this source. The principal factors governing the occurrence of mill scale corrosion are:

    (a) Rolling mill practice as it affects mill scale formation.
    (b) Duration of weathering (plate yard storage and building period of the ship).
    (c) Climate.
    (d) The type of underwater paint selected.
    (e) The maintenance of the underwater paint, including frequency of docking in the first year or two of service.

Mill scale corrosion occurs when the relationship of the foregoing factors is unfavorable and the sea water is able to reach relatively large areas of mill scale and small areas of bare steel.

The surest way of avoiding mill scale corrosion is to pickle or sandblast the underwater plating before the vessel is delivered. However, freedom from mill scale troubles can be obtained generally if the weathering is adequate, the paint is suited for ap-

Figure 24—Effect of washcoat primer. The plate at left (1) was precoated with washcoat primer (0.0003-inch thick). All of the underwater body was then painted with a conventional five-coat bottom system. At the next docking, about four months later, the anti-corrosive paint was intact, in good condition and free from blistering on the washcoat primed plate. Some peeling of the anti-fouling coat occurred in the bottom right hand corner. The remainder of the conventional system on the adjoining plate (2) and elsewhere on the bottom had failed, even to bare metal in many locations.

plication over mill scale, and the owner docks the vessel at three- and six-month intervals during the first year. Nonetheless, the presence of large areas of mill scale under the bottom paint can constitute a threat for a number of years, standing by to cause trouble if the bottom protection is allowed to deteriorate.

Vessels undergoing repairs involving renewals of bottom plates are especially susceptible to mill scale corrosion unless they receive the same care in painting and frequent docking which is accorded a new ship.

Zincs or Scandinavian irons do not necessarily pro-
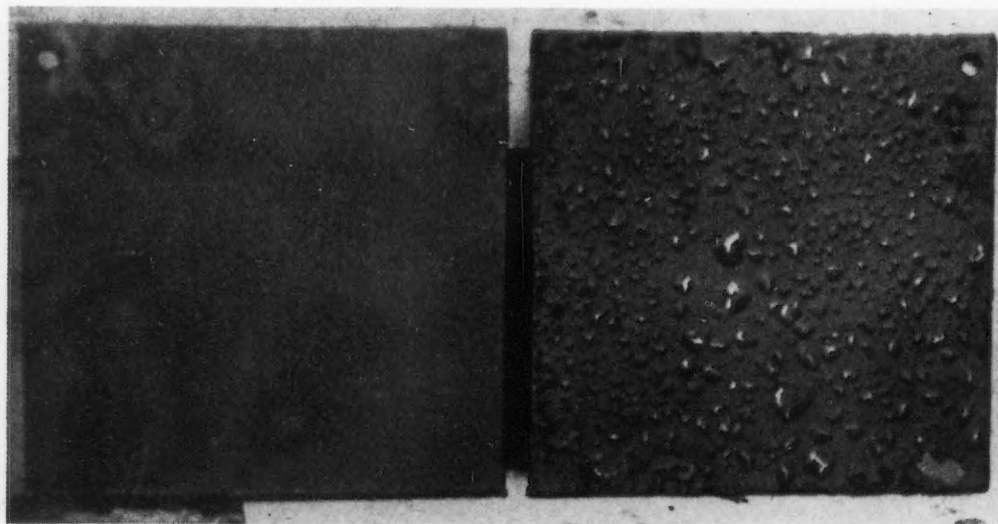
Figure 23—Test panels showing the beneficial effect of a washcoat primer in preventing blistering of paint. Both panels were sandblasted. Plate at left was coated with one coat of washcoat primer (0.0003-inch thick). Both panels were next painted with four coats of a conventional marine paint and immersed in sea water at Duxbury, Mass. Photograph was taken at 8 weeks—note extensive blistering up to ½-inch in diameter in panel at right. The first evidence of blistering on the panel at left occurred at 21 weeks immersion and at 40 weeks the blisters were scattered and less than 1/16-inch in diameter.

tect the hull by sacrificing themselves (as in cathodic protection) but by shouldering most of the burden of corrosion caused by the propeller on the bare steel in its vicinity—and in effect concentrating the attack on replaceable "doublers" which are not structural members.

Acknowledgment

APPENDIX

Treatment of Underwater Plating After Removal of Mill Scale

When mill scale is removed by pickling, sandblasting, or grinding, it leaves the bare surface of the steel in an active state. It will start to rust immediately and, in the case of sandblasted steel painted with a conventional four-coat marine bottom painting system, it is almost sure to blister prematurely when exposed to salt water as shown in the right-hand panel of Figure 23. This blistering tendency presents a real painting problem and special surface preparation is recommended generally to avoid it.

The usual pickling bath for removing mill scale consists of about a 5 percent by vlume aqueous solution of sulfuric acid maintained at a temperature of about 170 degrees F. This will descale the plate in about 20 minutes. Lower temperatures can be used but the time for descaling is increased proportionately. The acid pickling is followed with a water rinse, also at 170 degrees F. At this stage rusting will start immediately unless the surface is passivated. This is accomplished in a third bath consisting of 98 percent water and the balance a mixture of sodium dichromate and phosphoric acid. This bath is maintained at a minimum temperature of 195 degrees F and the immersion time is from five to ten minutes. This chemical treatment leaves a phosphate-chromate skin on the metal, which forms an excellent base for paint and has in itself some corrosion-inhibiting properties. It is advisable to paint the plate as soon as practicable after pickling.

A similar treatment, consisting of hosing down with a 2 percent phosphoric acid aqueous solution, is often recommended after sandblasting. In the case of wet sandblasting, the phosphoric acid sometimes is added to the water used in the blasting operation. The author's only experience with this cold phosphoric acid treatment was not encouraging. The underwater body of a vessel was sandblasted and several plates were treated with the phosphoric acid solution. The entire bottom was then painted with a conventional five-coat system. When the vessel was docked three months later, extensive blistering had occurred

TABLE V
Life of Typical Conventional Paint Systems With and Without Washcoat Primer on Sand-Blasted Steel

PAINT	Initial Sign of Failure (Months)	Total Failure (Months)
Paint A: 2 Coats Anti-Corrosive. 2 Coats Anti-Fouling.	2	5
Paint A: 1 Coat Washcoat Primer. 2 Coats Anti-Corrosive. 2 Coats Anti-Fouling.	7	12
Paint B: 2 Coats Primer. 1 Coat Anti-Corrosive. 1 Coat Anti-Fouling.	1½	4
Paint B: 1 Coat Washcoat Primer. 2 Coats Primer. 1 Coat Anti-Corrosive. 1 Coat Anti-Fouling.	Good at 6½ Months	Good at 6½ Months

over the entire bottom and there was no significant difference between the plates treated with the phosphoric acid and those untreated.

Other chemical treatments have been suggested after sandblasting, such as a sodium dichromate-trisodium phosphate wash. The author has found this system to be definitely harmful, which is not surprising since trisodium phosphate is one of the main ingredients of some paint removers.

In the author's experience, the surest way to avoid blistering trouble after mill scale removal on the underwater body is to coat the plating with a washcoat primer. These washcoat primers are an interesting development of the last war. They should be looked on more as a surface treatment than as a protective coat. They consist basically of two component parts, a pigment (usually zinc or lead chromate) carried in a synthetic resin, which is thinned just before application with a mixture of phosphoric acid and alcohol.

The action of the paint is as follows: the alcohol and phosphoric acid combine with any moisture present on the plate and attack the steel to form a phosphate coating. This phosphate coating is naturally sticky and provides excellent adhesion for the synthetic resin-chromate material. The chromate pigments provide additional protection, since they are among the most effective for suppressing rust formation under the paint film. These primers dry rapidly, usually within one or two minutes. Figure 23 illustrates the effectiveness of the washcoat primer in suppressing blistering on sandblasted surfaces exposed under water. Table V shows how these washcoat primers will extend the life of a conventional marine paint.

In the author's opinion, the washcoat primer paints constitute one of the significant advances in marine paint technology. The author has had first-hand experience with a number of vessels painted with these primers after sandblasting and under various conventional paint systems. Without exception the performance of the entire paint system has been greatly improved and there have been no premature failures due to blistering. Contrasting this, the same conventional paints when applied to sandblasted bottoms

without the washcoat primer have failed by blistering within four months. Figure 24 is an interesting example and shows a sandblasted ship where the paint manufacturer objected to the use of a washcoat primer under his paint. However, one plate was treated and the comparison between adjacent plates is significant.

Unless adequate precautions are taken after pickling or sandblasting or any other mechanical form of mill scale removal (chipping, grinding, etc.), premature paint failure due to blistering is almost sure to be encountered.

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34. J. Montgomerie and W. E. Lewis. "Corrosion in Hulls of Merchant Vessels." *The Institution of Engineers and Shipbuilders in Scotland Transactions,* **LXXV** (1932). Discussion by H. A. Gibbs.
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36. J. Montgomerie and W. E. Lewis. "Corrosion in Hulls of Merchant Vessels." *The Institution of Engineers and Shipbuilders in Scotland Transactions,* **LXXV** (1932). Discussion by U. R. Evans.
37. A. C. Redfield. "Interaction of Anti-Fouling Paints and Steels." O. S. R. D. Report No. 5053, 1943.
38. T. P. May, G. S. Gordon and S. Schuldiner. "Anodic Behavior of Zinc and Aluminum-Zinc Alloys in Sea Water." Contribution from the Naval Research Laboratory, Office of Naval Research, Washington 20, D. C.
39. F. L. LaQue. Private communication.
40. H. A. Humble. "Cathodic Protection of Steel Piling in Sea Water." *Corrosion,* **5**, No. 9 (1949) Sept.
41. Reported at Wrightsville Beach Informal Conference, June, 1950, sponsored by The International Nickel Company, Inc., 67 Wall Street, New York 5, N. Y.
42. G. L. Christie. "Cathodic Protection of an Active Ship in Sea Water." Naval Research Establishment, Halifax, Canada.
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(End Part I. Part II will be published in Corrosion, February, 1952.)

Topic of the Month

Aluminum Alloys
for Handling
And Storage of
Fuming Nitric Acid

By W. W. BINGER*

Figure 1—Aluminum alloy drum approved by the Interstate Commerce Commission (Specification 42B) for shipment of nitric acid (82 per cent by weight and above).

HISTORICALLY SPEAKING, the use of aluminum alloys for the handling and storage of nitric acid is not new. Aluminum alloys have been used for chemical equipment in the manufacture of nitric acid for a number of years. Aluminum alloys are used commercially for reaction vessels in which ammonia is catalytically oxidized, condensers for the concentration of the acid, as well as pressure piping and for many units in processes where nitric acid is one of the reactants. For example, in the manufacture of nitric acid base explosives, the non-sparking property of aluminum, as well as its resistance to corrosion, is used to advantage. Aluminum evaporators, crystallizers, prilling towers, hot and cold solution tanks, tank cars and piping are being used for the processing and handling of ammonium nitrate, thereby avoiding harmful contamination.

Extensive tests conducted at the Aluminum Research Laboratories revealed that aluminum alloys were very resistant to corrosion by concentrated nitric acid solutions. As a direct result of this investigation, Interstate Commerce Commission approval was obtained for shipment of nitric acid (82 percent by weight or above) in aluminum drums of the type shown in Figure 1, meeting specification 42B. In 1948 the Metal Packages Committee of the Manufacturing Chemists Association published the results of tests run in four independent laboratories in which various materials of construction for shipping containers, including aluminum alloys 3S and 99.6 percent aluminum were exposed to 93-98 percent nitric acid at temperatures up to 130 degrees F. It was concluded that the aluminum alloys tested were well-suited for nitric acid service, thereby confirming the ICC approval for shipment of strong nitric

* Chemical Metallurgy Division, Aluminum Research Laboratories, New Kensington, Pa.

acid (82 percent by weight or above) in aluminum drums. Although the data presented in Figure 2 were obtained using 2S-H14 aluminum, other data indicate that alloys 3S, 4S, 52S, 61S, 63S, 43 B214 and 356 would perform comparably in nitric acid solutions above 82 percent by weight.

To date, fourteen ICC approved 61S aluminum alloy tank cars have been built for nitric acid service. These cars handling 95-99 percent by weight nitric acid require surprisingly little maintenance; the oldest of these have been in continuous service over ten years. A recent examination of one of these cars after six and one-half years service substantiated the observations that the rate of attack decreases with the length of exposure. It was found that the inner surface of this tank car was virtually unaffected. However, the depth of penetration in the car, if calculated from laboratory data of one month duration, would have been 0.035-inch in six and one-half years. It was obvious from the examination that the attack was for all practical purposes self-limiting under actual service conditions.

Aluminum storage tanks have been in continuous service for over fifteen years handling 88 percent acid up to operating temperatures as high as 50 degrees C (122 degrees F). Aluminum alloys can be used for handling nitric acid above 50 degrees C (122 degrees F); however, consideration should be given to the application involved. For example, one nitric acid plant uses an aluminum heat exchanger to cool 97 percent by weight nitric acid (15 tons/day) from about 80 degrees C (176 degrees F) to 20 degrees C (68 degrees F).

Many aluminum alloys are highly resistant to corrosion by concentrated nitric acid solutions. However, taking into account such additional factors as availability, ease of fabrication and mechanical strength, it is believed that the fol-

lowing general alloy recommendations can be made:

	Order of Alloy Selections
Shipping Drums	3S, 99.6% Al, 4S, 52S
Storage Tanks	3S, 99.6% Al, 4S
Tank Cars	61S-T6, 52S
Piping	3S, 61S, 62S, 63S
Castings	356, 43 & B214

Some applications may require higher strength alloys despite the penalty of more difficult fabrication procedures. For such items, tests have indicated that the stronger alloys, such as 14S-T4, 14S-T6, 24S-T3 and 75S-T6, are resistant at room temperatures to fuming nitric acid.
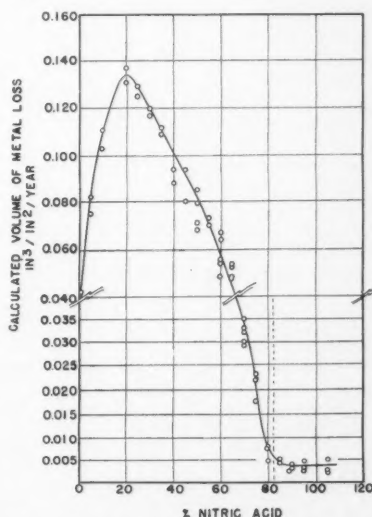

Figure 2—Effect of concentrations of nitric acid solutions at room temperature on the resistance of 2S-H14 to corrosion.

Greater Boston, Central Oklahoma Sections Added

Fair Praises South Central Region on Corpus Christi Meeting

Metropolitan New York Section Chairman W. F. Fair, who attended the October South Central Region meeting at Corpus Christi, Texas, highly complimented the region on the quality of the technical program and on the non-technical aspects of the meeting at a November 7 meeting of New York Section.

About 91 members and guests were present to hear Sam Tour of Sam Tour & Co., Inc., give an illustrated lecture on accelerated corrosion testing and Ward E. Pratt of Worthington Pump and Machinery Co., Harrison, N. J., discuss high velocity corrosion testing methods. Mr. Pratt's slides showed results of galvanic corrosion caused when iron pumps are connected in lines with lead tanks.

C. O. Evans of Phelps-Dodge Corp., New York, showed a motion picture on cavitation corrosion in which experimental work conducted by the navy was presented. The pictures showed formation and disappearance of air bubbles on streamlined specimens suspended in a channel of flowing water.

Mr. Fair recommended attendance, by everyone who possibly could go, at the 1952 Galveston Conference March 11-14.

John Swift of Lever Brothers, Cambridge, Mass., was present at the meeting as an observer. He is in process of forming Boston Section.

Philadelphia Section Names New Officers

In spite of a traffic-snarling snowstorm a record attendance of 85 heard Mars G. Fontana, of Ohio State University speak at a joint North East Region and Philadelphia Section meeting at the Poor Richard Club, Philadelphia, December 14. Dr. Fontana's topic was "Corrosion and Its Prevention."

A Christmas party and dinner preceded the regular meeting.

Elected for 1952 were the following new officers: W. Ronald Briggs, of W. A. Briggs Co., chairman; Edward S. Brink, of American Viscose Corp., vice-chairman and John S. Pettibone, American Society for Testing Materials, secretary-treasurer.

Next regular meeting of the section will be February 8 at the Poor Richard Club.

NACE MEETINGS CALENDAR

January

3—Pittsburgh Section. Stress Corrosion, by E. H. Dix, Jr., Aluminum Company of America.

7—North Texas Section. Venus Restaurant, Dallas, 6:30 p.m.

8—Eastern Wisconsin Section and ASME joint meeting. F. L. LaQue, speaker on corrosion testing. Milwaukee Engineering Society building.

8—Houston Section. The Identification, Specification and Application of Straight Chromium Alloy Steels to Petroleum Processing and Production by George C. Kiefer, Allegheny-Ludlum Steel Corp., Brackenridge, Pa.

8—Teche Section.

10—Southwestern Ohio Section. Joint meeting with the American Society for Metals at Engineer's Club, 6:30 p.m., Woodburn and McMillan St., Cincinnati. F. L. LaQue of The International Nickel Co., Inc., New York, speaker.

15—Chicago Section. Factors Influencing Corrosion of Mild Steel and Mild Steel Welds in Process Equipment, by R. A. Huseby, A. O. Smith Corp.

17—Detroit Section. Engineering Society's Rockham Building, Farnsworth Street and Woodward Ave., Detroit.

30—Sabine-Neches Section. Graphitization of Steel at High Temperatures, by John Cook, Humble Oil and Refining Company, Baytown.

February

7—Pittsburgh Section. Corrosion Problems in Industry, speaker to be announced.

8—Philadelphia Section. Poor Richard Club, Philadelphia.

12—Houston Section. Joint meeting with University of Houston Junior Section. Program: Color sound motion picture, "Elementary Corrosion," supplied by Allegheny-Ludlum Steel Co. Second part of the program will be a talk by a University section student on a pipe line subject.

19—Chicago Section. Cathodic Protection and Common Sense by D. C. Glass, Pure Oil Company.

27—Sabine-Neches Section. Meeting at Lake Charles. Refinery Painting, by W. B. Cook, Gulf Oil Corp.

Association Now Has 26 Local Organizations

The addition of Greater Boston Section and Central Oklahoma Section brings the number of organized sections in the National Association of Corrosion Engineers to 26. This is an increase of six over the 20 which were organized in January, 1951. There have been three new sections organized in less than two months, the most recent besides the two mentioned being the Teche Section, organized in the South Central Region at Lafayette, Louisiana in November.

During the year there has been a net increase in membership of approximately 600.

The organization meeting of Greater Boston Section was held December at Smith House, Cambridge, Mass. with 30 NACE members from Boston and vicinity present.

Objectives of NACE and the new section were explained and discussed and officers were elected as follows: Edwin J. Titsworth, Koppers Company, Inc., Boston, chairman; John Swift, Lever Bros. Co., Cambridge, vice-chairman; J. D. Bird, The Dampney Co. of America, Boston, secretary-treasurer.

After the organizational business meeting H. H. Uhlig of Massachusetts Institute of Technology spoke on the development of scientific knowledge about corrosion and its control.

Official representatives of North East Region present were T. P. May and W. F. Fair, Jr. John Mason, Jr. of Metropolitan New York Section was present as a guest.

Central Oklahoma Section, recently organized by NACE members in the vicinity of Oklahoma City, has elected officers as follows: F. W. Fullerton, Southwestern Bell Telephone Company, president; J. E. Johnson, Oklahoma Natural Gas Company, vice-president; L. J. Vaneigh, Oklahoma Natural Gas Company, secretary-treasurer and W. H. Meigs, Phillips Petroleum Company, secretary-trustee.

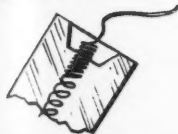The section currently consists of 33 members but W. H. Meigs predicts a rapid growth.

Western New York Aids In Industrial Conference

Western New York Section has been asked to participate in an industrial conference scheduled to be held at Hotel Statler, Buffalo, New York, April 29. W. O. Binder, Union Carbide and Carbon Co. Research Laboratories, Niagara Falls, N. Y., and vice-chairman of Western New York Section, has been named chairman of the Corrosion Panel.

Fruitful Board Meeting Is Held at Houston Nov. 30

The board of directors of the National Association of Corrosion Engineers met at the Rice Hotel, Houston, November 30 and December 1. Several decisions were made, especially some affecting the 952—Galveston Conference, and steps were taken to establish policy of the association in connection with several suggested innovations in association activities.

Principal policy matters discussed were:

1. What the association would suggest to persons in Canada and the Panama Canal Zone respecting formation of local organizations affiliated with NACE. The board also discussed implications of possible similar requests which might be reecived from foreign countries, such as from Japan, where there already are NACE members among scientists actively working on corrosion control.

2. What the position of the association would be relative to suggestions which have been made to the board whereby prizes would be offered authors of technical material published in CORROSION.

3. Concentration of publicity matters on association activities at Central Office in the interest of speed and efficiency. Central Office will plan, prepare and secure approval of publicity items for distribution to members and others. The cooperation of Central Office will be offered sections in carrying out effective publicity.

4. Considered what the association's position would be relative to a proposal advanced by F. L. LaQue whereby technical material relating to timber, concrete and other marine shore installations would be published by the association. The discussion indicated the board favored considering material metal-connected, or applicable as a substitute for or alternate to metal but did not favor extending the association's interests to such matters as marine biology.

The board also reaffirmed previously made decisions in declining the offer of subscription agencies to sell association publications and refraining from becoming a sales agent handling publications for other publishers.

The policy matters were in part referred for consideration to the policy and planning committee and in others the president was authorized to reply in writing for the association.

Galveston Conference Issues

Several significant decisions pertaining to the Galveston Conference were made:

1. A barbecue and entertainment will be given one night during the conference on the Municipal Pier at Galveston. This is in addition to the annual banquet.

2. Technical committee meetings will be held throughout the conference and not on Monday, March 10, only, co-ordinated with the technical program.

Abstract Service Fee Set

The board set the cost of the 1952 Abstract Card Service subscription at $75. A charge of $100 for supplying to new subscribers complete files of 1951 abstract cards was authorized. A deci-
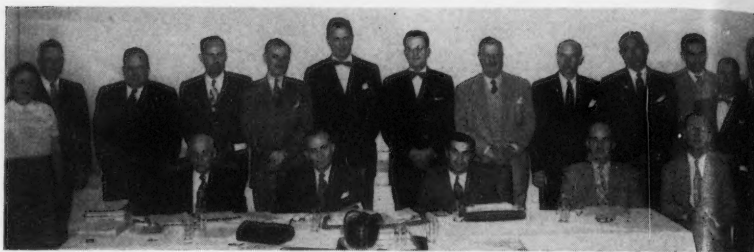
Members of the NACE Board of Directors and others who met November 30-December 1 at the Rice Hotel, Houston. Standing, left to right, Ivy M. Parker, Editor of Corrosion, Plantation Pipe Line Co., Bremen, Ga., representing F. L. LaQue, unable to attend; Frank L. Whitney, Jr., Monsanto Chemical Co., St. Louis, Mo.; C. P. Larrabee, United States Steel Co., Vandegrift, Pa.; L. A. Hugo, Phillips Petroleum Co., Bartlesville, Okla.; L. B. Donovan, Consolidated Edison Co. of New York; Charles G. Gribble, Jr., Metal Goods Corp., Houston, local arrangements chairman for the 1952 Galveston Conference; H. A. Humble, Dow Chemical Co., Midland, Mich.; S. D. Day, S. D. Day Co., Houston; Walter F. Rogers, Gulf Oil Company, Houston, Texas, general chairman, 1952 Galveston Conference; Vance N. Jenkins, Union Oil Co. of California, Wilmington, Cal., past president; Norman Hackerman, University of Texas, Austin, educational committee chairman; T. F. P. Kelly, James E. Mavor Co., Houston; V. V. Malcom, The Philip Carey Manufacturing Co., Cincinnati, Ohio. Seated: A. B. Campbell, executive secretary NACE; N. E. Berry, Servel, Inc., Evansville, Ind., president; Mars G. Fontana, Ohio State University, Columbus, vice-president; R. A. Brannon, Humble Pipe Line Co., Houston, treasurer; Robert L. Bullock, Interstate Oil Pipeline Co., Shreveport, La., technical program chairman 1952 Galveston Conference.

sion based on costs will be made at Central Office before the association will offer to sell back issue cards, however. Requests for back issue cards will be accepted and accumulated until a sufficient number to make the reprinting operation practical have been received.

Other miscellaneous decisions by the board included:

1. The 1952 Annual Directory of NACE Membership will be published in the March issue of CORROSION. Reprint copies of the directory will be offered for sale.

2. The association will set up machinery whereby supplementary subscriptions to CORROSION will be sold to those who wish to have bound copies prepared. The association will attempt to make a non-exclusive arrangement with a binder whereby those who wish to do so may buy a subscription, have it sent monthly to the binder, and advise the binder in what manner the binding shall be done at the end of the year.

As in current arrangements with binders, NACE will not participate in the contract for binding operations.

Those who wish to do so may order supplementary copies sent to a binder of their own choice.

The charge for the supplementary subscription was not determined.

3. The board authorized the executive secretary to negotiate for space for the 1954 Conference, to be held during the first half of March.

4. Further study of a plan to provide a retirement program for NACE employees was authorized.

5. The executive secretary was instructed to investigate the feasibility of advancing the schedule of voting for national officers so a decision would be known earlier.

South Central Region entertained members of the board and others attending the meeting at luncheon Friday. W. C. Waldrip, vice-chairman of the region, acted as host in the absence of M. C. Fleming.

Baltimore Section Hears Of Aluminum Heat Exchanger Advantages

J. S. Hamilton of the Development Division, Aluminum Company of America, addressed 35 members and 10 guests of Baltimore Section December 13 at a dinner meeting. His topic, "Aluminum Heat Exchangers in Corrosion Control," included application of aluminum heat exchangers for steam, water and various chemical services. Aluminum can be substituted for other materials frequently used, he advised. Inhibitors and electrolytic insulation are beneficial in controlling corrosion, he said.
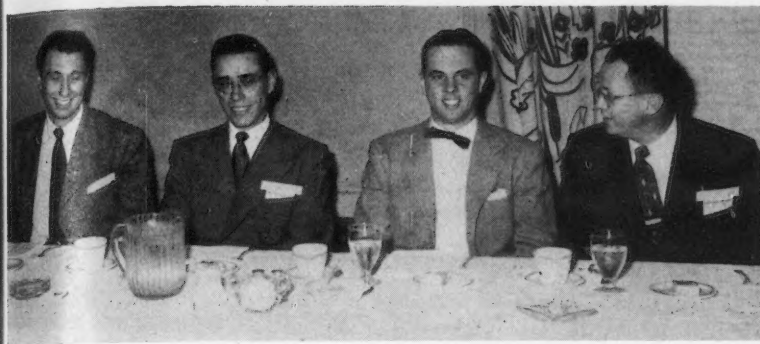
Certificates Approved For Section Recognition

A certificate, which will be presented to all sections of NACE after having been suitably signed and sealed by officers of the association was approved at the association's board meeting in Houston November 30-December 1. The form for the certificate was prepared by E. P. Noppel's policy and planning committee.

Henceforth, new sections, when their request for recognition has been approved, will receive a certificate. All present sections will be issued certificates.

Pittsburgh Section Hears Harold Rosenbloom

Scheduled for the December 6 meeting of Pittsburgh Section was a talk by Harold Rosenbloom, Thompson & Company, Oakmont, Pa. on "Chemical Treatment of Surface for Protective Coatings."

PANEL MEMBERS—Members of a panel which discussed "Welding for Corrosion Service in Chemical and Allied Industry," at St. Louis, Mo., are Russel Royer, Midwest Piping and Supply Company, and Richard Weeks, Shell Oil Company, representing American Welding Society, and Frank L. Whitney, Monsanto Chemical Company and Phillip Smith, Nooter Corporation, representing NACE.

Welding For Corrosion Service Is Discussed

A panel discussion on "Welding for Corrosion Service in the Chemical and Allied Industry," was held November 9 at Forest Park Hotel Ballroom, St. Louis, Mo. The joint meeting of the American Welding Society and NACE was attended by 52 members and guests of both organizations.

Members of the panel were Russel Royer, Midwest Piping and Supply Company and Richard Weeks, Shell Oil Company, representing American Welding Society and Frank L. Whitney, Monsanto Chemical Company and Phillip Smith, Nooter Corporation, representing NACE. The discussion was moderated by Ernest Meyer.

Whitney presented a resume of what happens to carbon steel in various environments, and Weeks, replying to a question "In what corrosion service do the chrome steels excel?" presented authoritative data. Smith outlined precautions needed in selecting chrome steels, and provoked some controversy in the panel by his discussion of the merits of post-heat treatment.

Royer discussed aspects of extra low carbon stainless steels, emphasizing fabrication difficulties.

Corrosion Testing to Be Joint Meeting's Topic

F. L. LaQue of The International Nickel Co., Inc., New York, will address a joint meeting of Eastern Wisconsin Section and the American Society of Mechanical Engineers on corrosion testing January 8 at Milwaukee Engineering Society Building.

New officers were elected as follows at a meeting December 3: Harold F. Haase, Marquette University, Milwaukee, chairman; Irving S. Levinson, Ampco Metal, Inc., Milwaukee, vice-chairman; R. E. Wicen, Chain Belt Co., Milwaukee, secretary-treasurer. Directors also were elected as follows: K. E. Wooldridge, E. W. Gifford, R. A. Seidenstricker, C. E. Imhoff, W. A. Deringer and L. J. Beckwith.

C. P. Larrabee of United States Steel Company presented a talk on "The Effect of Environment and Composition on the Corrosion of Steel" at the November meeting of the section. Listeners' comments indicated they had received information new and valuable to them. Attendance of about 40 members and guests at this meeting was considered exceptionally good by section officers in view of travel difficulties posed by snow.

L. P. Sudrabin of Electro-Rust-Proofing Corp. addressed the December 3 meeting on cathodic protection.

Southwestern Ohio and ASM Joint Meeting To Hear F. L. LaQue

F. L. LaQue of The International Nickel Co., Inc., New York City, will address a joint meeting of the American Society for Metals and the Southwestern Ohio Section NACE at the Engineer's Club, Cincinnati, Ohio, January 10. The meeting previously had been publicized for January 17. The dinner gathering will begin at 6:30 p.m.

James Crane, of Cincinnati Chemical Works, Robert Paul of Emery Industries and Ed Ritter of Cimcool Division of Cincinnati Milling Machine Company spoke on corrosion problems in their respective industries at the November 27 meeting of the section. The dinner meeting was held at Shuller's Restaurant, Reading, Ohio with 24 members and guests present.

A general discussion followed an illustrated talk on boiler feed water corrosion by Joseph Engel of Dayton Power and Light Company October 30. There were 15 members and six guests at the dinner meeting held at Shuller's Restaurant, Reading, Ohio. Mr. Engel showed specimens of boiler tubes and other equipment that had failed as a result of high temperatures and pressures involved in high pressure steam boiler operations.

Everett Gosnell, North Central Regional Chairman spoke briefly on tentative plans for a regional meeting at Cleveland, Ohio in April, 1952. He explained this meeting would be helpful for those who were unable to attend the national meeting at Galveston March 10-14.

New officers were elected as follows at a meeting December 3: Harold F. Haase, Marquette University, Milwaukee, chairman; Irving S. Levinson, Ampco Metal, Inc., Milwaukee, vice-chairman; R. E. Wicen, Chain Belt Co., Milwaukee, secretary-treasurer. Directors also were elected as follows: K. E. Wooldridge, E. W. Gifford, R. A. Seidenstricker, C. E. Imhoff, W. A. Deringer and L. J. Beckwith.

L. P. Sudrabin of Electro Rust-Proofing Corp., addressed the December 3 meeting on "Some New Views on Cathodic Protection."

North Texas Section Officers Are Reelected

Current officers of North Texas Section, H. L. Bilhartz, chairman; J. C. Spalding, Jr., vice-chairman and N. P. Chesnutt, secretary-treasurer were unanimously reelected at a meeting December 3 at Fort Worth. The meeting was attended by 24 members and 14 guests.

Norman Hackerman of the University of Texas spoke on "Recent Researches on Corrosion Inhibition," which concerned the use of radioisotopes in measuring inhibitor efficiency.

A motion picture "Let's Get Out of This Muddle," dealing with the critically serious condition of the nation's highway system and the need for concerted action in remedying it, was shown.

Next meeting of the section is scheduled January 7 at 6:30 p.m. at the Venus Restaurant, Dallas.

Tulsa Section to Hold 3-Day Corrosion Short Course at Tulsa on February 27 Through 29

Fleming Elected Head Of South Central Region

M. C. Fleming, Phillips Petroleum Co., Bartlesville, Okla., was elected chairman of South Central Region for 1952. Other officers elected were H. E. Waldrip, Gulf Oil Corp., Houston, vice-chairman and T. S. Moffatt, Jr., Columbia-Southern Chemical Co., Corpus Christi, secretary-treasurer.

Overcoming Restrictions In Solving Corrosion Problems Is Discussed

W. Z. Friend, of the Development and Research Division of The International Nickel Co., Inc., New York told 83 members and guests of Houston Section at a December 11 dinner meeting there are several ways to compensate for materials restrictions in planning corrosion mitigation measures. His address "Solving Corrosion Problems Under Metal Restrictions," emphasized the role of metal selection.

B. B. Morton, also with International Nickel, reviewed service data on alloyed tubing in a talk titled "The Performance of Alloy Tubing in Gas Condensate Wells."

Mr. Friend's suggestions included modification of design, proper use of inhibitors, cathodic protection and non-metallic materials. The role of alloying elements in stainless steels was explained to show some specifications may be down graded without seriously affecting corrosion resistance. Clad steels, and thinner claddings or platings may be adequate where solid materials are used now, he said. Control of concentrations, aeration, velocity, turbulence, galvanic effects and stress conditions and elimination of troublesome joints and crevices all offer promise.

Mr. Morton told of installations of alloy oil well tubing, largely as a result of the findings of NACE Technical Practices Committee 1 field tests. In many applications for sweet condensate wells the alloy tubing has served well, he reported, but some stress corrosion problems have been encountered in sour condensate wells.

He outlined results of some laboratory tests involving stressed specimens in a hydrogen sulfide environment, expressing hope future NACE tests in this area will consider the role of stress.

A three-day corrosion school has been scheduled by Tulsa Section at Mayo Hotel, Tulsa, February 27-29. This school, for pipeliners, will be similar to those held during the past two years.

Emphasis will be on acquainting field personnel with the why and how of corrosion control so they may participate more effectively in this phase of their companies' operations. Instructions is on a non-technical level.

A series of discussion periods will be held at the hotel and a field trip will provide a demonstration of the why and how of corrosion control. The program will be conducted by pipeline men of broad experience in the mitigation of corrosion and will cover the following subjects: corrosion and its control, rectifiers, expendable anodes, corrosion surveys, use of pipe line locators, use, care and handling of instruments and equipment; coating materials and application and installation and testing of insulating flanges and nipples.

Inquiries for additional information and registration forms should be addressed to Y. W. Titterington, Standard Magnesium Corp., Box 1424, Tulsa, Oklahoma.

Sabine-Neches Section Hears W. Z. Friend

Problems facing the corrosion engineer under materials restrictions were outlined by W. Z. Friend, assistant head of the corrosion engineering section of The International Nickel Co., Inc., New York City at a December 6 meeting of Sabine-Neches Section. The meeting was held at Mont Leon Delicatessen, Beaumont, Texas with 30 members and 8 guests present.

Mr. Friend, speaking on the topic "Solving Corrosion Problems Under Material Restrictions," said the ingenuity and ability of the corrosion engineer is being challenged as never before. He recommended the following five-step method of approach to corrosion problems: 1—Selection of metals more readily available. 2—Design or operating changes. 3—Use of inhibitors or passivators. 4—Cathodic protection. 5—Use of non-metallic materials. A spirited question and answer period followed his talk.

South East Region's Fall Meeting at Atlanta Draws 50

Fifty were present for the fall meeting of South East Region at the Ansley Hotel, Atlanta December 5. The meeting was featured by three talks, a forum and several films, including the "Manhattan Spotlight" feature which was broadcast over television at New York City during the 1951 annual meeting there.

Papers were given as follows during the afternoon session: Comparative Tests of Water Tank Protection Methods and Current Status of Anti-Tuberculation program by A. T. Storey, Atlanta Water Works; Cathodic Protection of Buried Underground Cable by J. P. McArdle, American Telephone and Telegraph Co., Atlanta.

An open forum discussion was held at 4 p.m. and at 5:30 p.m. there was a Fellowship Hour and showing of films. E. G. Holmberg, Alloy Steel Products Company, Linden, N. J. was dinner speaker on "Metallurgical Factors in Corrosion."

Attendance at Western Region Meeting Is 175

Attendance at Western Region's meeting at Los Angeles November 9 was 175, L. L. Whiteneck, region chairman, reported. Eight technical papers were presented, all of which are expected to be submitted for publication in CORROSION.

The six-society meeting preceding the NACE conference was attended by 715. F. L. LaQue, International Nickel Co., Inc., and a past president of NACE, delivered the 1951 Marburg Lecture.

UCLA Corrosion Short Course to Open Feb. 4

A fee of $35, which covers cost of transactions, will be charged for a short course in corrosion to be given February 4-9 at University of California, Los Angeles. The Department of Engineering, University of California, and the National Association of Corrosion Engineers are sponsors.

The course will cover fundamentals, materials of construction, environment, protective coatings, cathodic protection, chemical treatment and specific industrial applications. Further information and a final program are available on request from Department of Conferences and Special Activities, University Extension, University of California, Los Angeles.

An index covering all technical material published in Corrosion for the years 1945-50 inclusive was published in the December 1950 issue. Copies of the issue are available. The indices may be extracted and used separately if desired.

Corrosion Inhibitor Injection Discussed

"Methods of Injecting Corrosion Inhibitors in Wells and Lines" was the topic of a talk by S. A. Huckleberry of Dowell Incorporated at a dinner meeting of Corpus Christi Section November 28. Fifteen members and 10 guests were present.

No meeting of the section was held during December.

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Reports of technical committees of the association are available for purchase by members and non-members.

Film on Rail Steel Offered for Viewing

A 35-minute, 16-mm color film offered free for showing to colleges and technical and trade association by the Rail Steel Bar Association, 35 South Dearborn St., Chicago 3, Ill., depicts the manufacture of new rails and conversion of used rails into steel sections. Application of these sections to agricultural implements, mining, furniture and many other fields is detailed. Reclamation and conservation of steel are recurring themes. An application for loan of the film may be obtained on request.

NACE Awards

Names of the 1952 recipients of the annual Speller and Whitney Awards will be published in the February issue of Corrosion.

BOOKLETS

Control of Pipe Line Corrosion by O. C. Mudd.
Per Copy, postpaid................ $ 1.25
(5 or more copies to one address, per copy, $1)
Report of the Correlating Committee on Cathodic Protection. Bulletins I, II, III, IV. Per Copy, postpaid............. $ .50
Directory, American Coordinating Committee on Corrosion (1947). Per Copy.....$ 2.00

TECHNICAL REPORTS

TP-3 First Interim Report on Ground Anode Tests. Publication 50-1.
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Bibliographic Survey of Corrosion, 1946-47
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Postpaid to NACE members, per copy $ 3.00
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Address Orders and

Remittances to

NATIONAL ASSOCIATION

OF

CORROSION ENGINEERS

919 Milam Building

HOUSTON   **TEXAS**

University of Houston's 18-Week Course In Corrosion to Start Registration Jan. 29

NACE Board Asks for Early Participation In Corrosion Courses

Early participation by the National Association of Corrosion Engineers in arrangements for short courses in which it is to be asked to participate will be required by the association's board of directors in the future, according to a decision reached at the November 30-December 1 board meeting in Houston. The association's executive committee must approve all requests for sponsorship or participation submitted by institutions organizing short courses. These requests should be directed to the board through Norman Hackerman, chairman of the education committee, which will make recommendations to the board concerning the courses.

The board believes early participation will prevent such confusion as has occurred in the past as a result of the formulation of plans which have not coincided with association policy.

The board also instructed the chairman of the educational committee to request, but not to require, institutions conducting short courses in which NACE is listed as a sponsor, to so establish registration fees that non-members of the association may be given the opportunity to apply portions of their registration fees toward memberships in the association.

Color Movie on Steel Foundry Made Available

"Steel With a Thousand Qualities," a 16-mm, 37 minute sound motion picture is available for free showings by industrial and manufacturing groups and technical organizations and educational groups. The motion picture, just completed by Lebanon Steel Foundry, Lebanon, Pa., is in full color and features uses of steel castings, showing foundry processes and manufacturing operations, electric furnace charging and tapping, permanent mold centrifugal casting and other operations.

Prints are available on request from Modern Talking Picture Service, Inc., 45 Rockefeller Plaza, New York 20, N. Y.

Corrosion Being Sent To Dutch Publication

Corrosion magazine is being sent to the Bureau for Industrial Documentation and Propaganada of the Netherlands so information concerning technical material published in it may be incorporated in the bureau's "Technical Bulletin," which is published monthly. Information will be given prospective subscribers to Corrosion, including translation assistance, where needed, so they can decide whether Corrosion would be beneficial to them.

An 18-weeks' course in corrosion will be given by the College of Engineering, University of Houston, beginning January 29 and continuing until the first week in June. The course will be divided into four major sections with one instructor per section to be selected from major industries.

The projected course will consist of two one and one-half hour sessions and one three-hour session weekly. Junior, senior and graduate students of the university are eligible to attend for credit and non-students interested in corrosion also may attend. These latter will be issued a certificate on successful completion of the course.

Registration will be on January 24 and 25.

While the course will be offered by the university without organizational collaboration, South Central Region NACE is cooperating with the college of engineering faculty in promoting the course.

Additional information may be obtained from Prof. J. R. Crump, Engineering Laboratory, University of Houston, Cullen Blvd., Houston 4, Texas.

ISC Surveys on Water Pipe and Microbiological Corrosion Are Started

Two surveys of the members of the Inter Society Corrosion Committee are now being conducted. They are designed to determine: 1—If there is need to organize a "Research Council on Internal Corrosion of Water Pipes," to solicit funds with which to sponsor research projects in this field, and 2—The extent to which member organizations of the committee are willing to cooperate with American Gas Association in investigating microbiological corrosion of pipe and pipe coatings. Delegates have been asked to supply answers to a series of questions on each of these points and sumbit them as the official positions of their respective organizations.

Sam H. Tour, chairman of the committee, in his letter transmitting the questionnaire on internal corrosion of water pipes, said the committee "has raised a question as to the need for the proposed research council in view of the current activities of many of its member organizations and many other research workers in the field of corrosion."

The questionnaire on this topic asks, among other things, what the interest of the answering organization is in the subject, whether cooperative investigations with other organizations will be considered, for descriptions of current studies in progress, their extent and status, as well as a committment on preference as to procedure.

The inquiry on microbiological corrosion is substantially of the same nature.

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Information about membership in NACE will be sent on request to persons interested.

Widespread Interest Is Shown in Program on De-Icing Salts Damage

Encouraging response to a survey made by Technical Practices Committee 19 on Corrosion by De-Icing Salts is reported by F. E. Kulman, Consolidated Edison Company of New York, chairman. The committee received 153 replies as a result of mailing questionnaires to approximately 300 NACE Corporate members and 100 additional companies. Of this number 95 expressed an interest in corrosion by de-icing salts.

Especially significant was the wide variety of industries in which icing salt corrosion is a problem. These included automobile, cable, chemical, electric power, gas, oil, railway, steam and water companies. There were 23 other industries in addition to these listed.

Type of Operations

Classification of returns by the type of operations showed the following: Educational and research 7, electrolysis committee 1, manufacturers 32, municipalities 3, transportation 13, utilities 38 and others 9.

Above ground corrosion by salt was important to 55 and underground corrosion to 59 of those interested.

The degree of interest expressed also was indicative of the widespread concern over this problem. Of those who replied to the questionnaire 90 wanted to receive reports; 29 to contribute experiences to a technical committee, 11 to contribute results of research already being performed, 18 who wanted representation on the technical committee and 3 others.

Evidence Is Qualitative

Mr. Kulman explained that evidence on the corrosive effect of salts appears to be of a qualitative nature only. Little quantitative data have been collected and what has been published has not been conclusive. One of the first committee jobs, he indicated, would be to plan and conduct a series of field tests to determine the corrosion rate of salt-free, salt and inhibited salt areas.

A comprehensive organizational diagram has been prepared for the committee's scope by Mr. Kulman. This includes assessment on geographical and seasonal bases of corrosion effects on all kinds of over and under ground plant and equipment, together with an examination of economic losses, remedial measures and the effect of salts on corrosion mitigative measures presently in use.

Anderson Talks to Power Group on Value Of NACE Cooperation

Advantages to electric power companies in helping promote control of corrosion by cooperation with the National Association of Corrosion Engineers was the theme of an address November 20 to members of the Petroleum Electric Power Association by H. H. Anderson, vice-president and general manager, Shell Pipe Line Corp., Houston. The

association met at the Shamrock Hotel, Houston, November 19-20. Mr. Anderson, chairman of the NACE membership committee, whose topic was "Why Power Companies Should Promote Corrosion Control," told his listeners, with frequent illustrations from material published in Corrosion, of the many advantages that might be expected.

Mr. Anderson briefly listed the principal causes of corrosion, indicated the magnitude of the problem and the size of the annual losses and then enumerated the various ways in which power companies might be expected to profit from belonging to NACE. Operating companies benefit by not having to include corrosion costs in charges for service, suppliers of corrosion preventives benefits from their fair profit and the public benefits by not having to pay corrosion costs, he said.
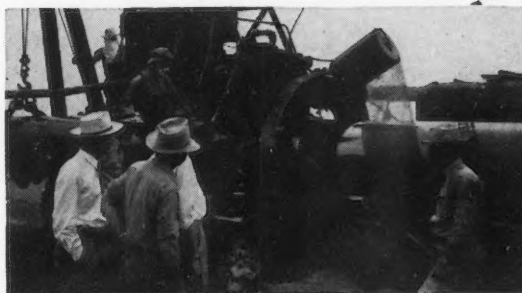
He concluded his talk by pointing out that current curtailment of civilian supplies of metals as a result of the rearmament program makes the conservation of metal a national requirement instead of merely an economic desirability.

British Industries Fair

The 1952 British Industries Fair will be held May 5-16, at London and Birmingham. It will occupy three exhibit halls, Earl's Court and Olympia in London and Castle Bromwich at Birmingham. Special train service between London and Birmingham will be provided.

Advance Program for '52 Conference Is Planned

An advance program for the 1952 Galveston NACE Conference and Exhibition to be held March 10-14 has been released by R. L. Bullock, technical program chairman. The program calls for the delivery of 32 technical papers in nine symposia, two round table discussions and the first-run showing of a technical motion picture in color on corrosion fundamentals. Mr. Bullock indicated some revision in the program is to be expected.

Plans have been made to issue an advance technical program for mailing to all NACE members about January 15.

Following is the tentative program:

Monday, March 10

9 a.m.—Registration begins and continues all day.
Committee meetings all day.
Exhibits set up all day.

Tuesday, March 11

9 a.m.—Committee meetings.
11 a.m.—General business meeting.
2:30 p.m.—Corrosion Principles Symposium. Chairman, Norman Hackerman, University of Texas.
Motion picture, "Corrosion in Action." There will be a 15 minute introduction by F. L. LaQue of The International Nickel Co., Inc., of New York City, producers of the film.
6 p.m.—Fellowship Hour.
Registration, Committee meetings and the exhibition will continue all day.

Wednesday, March 12

9 a.m.—Oil and Gas Industry Symposium. H. E. Waldrip, Gulf Oil Corp., Houston, chairman. Morning session on hydrogen sulfide stress cracking. Four papers scheduled.
9 a.m.—Chemical Industry Symposium. P. J. Gegner, Columbia-Southern Chemical Co., chairman; C. A. Co-

berly, Mallinckrodt Chemical Works, co-chairman. Three papers: Corrosion by Sulfur and Sulfur Compounds at Elevated Temperatures by W. Z. Friend and E. N. Skinner, International Nickel Co., Inc.; Kel-F Applications in Corrosive Systems by W. O. Teeters and L. C. Rubin, W. O. Kellogg Co.; Corrosion by Fluorine and Fluorine Compounds by Ralph Landau, Scientific Design Co., Inc.

2:30 p.m.—Oil and Gas Industry Symposium—Continued. Afternoon session on general corrosion in oil and gas production. Four papers: Acid Gas Study in Corrosion by W. F. Rogers and J. A. Rowe, Gulf Oil Company; Corrosion Testing Techniques by D. A. Shock, Continental Oil Company; Sour Crude Corrosion by J. A. Caldwell, Humble Oil & Refining Co.

2:30 p.m.—Refinery Industry Symposium. J. K. Deichler, Atlantic Refining Company, chairman. Two papers: A Laboratory Method for Evaluating Steam Condensate Return Line Corrosion Inhibitors by John Ryznar, National Aluminate Corp., Chicago.; EMF Measurements of Certain Stainless Steels by K. M. Huston, Armco Research Laboratories, Baltimore, Md.

2:30 p.m.—Marine Industry Symposium. Allen L. Alexander, Bureau of Naval Research, chairman. Three papers: Use of Magnesium Anodes for Protecting Inactive Ships, Corrosion Characteristics of 90-10 Cupro-Nickel in Sea Water, Organic Coatings for Internal Protection of Tankers. Registration, committee meetings and exhibition will continue all day.

Thursday, March 13

9 a.m.—Electrical and Communication

Industry Symposium. M. D. Fletcher, Illinois Bell Telephone Company, Chicago, chairman. Four papers.

9 a.m.—Chemical-Refinery Industries Combined Symposium. P. J. Gegner, chairman; J. K. Deicher, co-chairman. Four papers.

2:30 p.m.—Protective Coatings Industry Symposium. A. J. Liebman, Dravo Corp., chairman; L. L. Whiteneck, Long Beach Harbor Dept., co-chairman. Four papers: Protection of Offshore Production Equipment by H. L. Bilhartz, Atlantic Refining Co.; Coating Experiences With Cathodic Protection—Underwater by Ray Devolyu, C. A. Woolsey Paint Company; Values of Surface Preparation and/or Pretreatment for Use in Conjunction With Various Outstanding Paint Systems in Industrial and Marine Atmosphere by J. C. Hudson.

2:30 p.m.—Oil and Gas Transportation and Storage Industry Symposium. L. G. Sharpe, Humble Pipe Line Company, chairman; O. C. Roddy, Interstate Natural Gas Co. Inc., Monroe, La., co-chairman. Four papers.

7 p.m.—Annual banquet. Presentation of Whitney and Speller Awards. Registration, committee meetings and exhibition all day.

Friday, March 14

9 a.m.—Pipe Line and Underground Corrosion Round Table. Kirk H. Logan, Cast Iron Research Institute, Washington, D. C., chairman.

9 a.m.—General Corrosion Problems Round Table. R. B. Hoxeng, U. S. Steel Co., chairman; Frank L. Whitney, Monsanto Chemical Co., co-chairman. Exhibition will be open in forenoon.

Columbia Department Head Addresses AIChE

Thomas Bradford Drew, head of the department of chemical engineering at Columbia University, New York, delivered the Annual Lecture of the American Institute of Chemical Engineers at Atlantic City during the institute's meeting there December 2-5.

Chalmer Gatlin Kirkbride, vice president and director of Houdry Process Corp., was awarded the 1951 Professional Progress Award in Chemical Engineering, sponsored by the Celanese Corp. The award carries a prize of $1000.

Other meetings scheduled by the institute include: in 1952: March 16-19, Atlanta, Ga.; May 11-14, French Lick, Ind.; Sept. 11-13, Chicago; Dec. 7-10, Cleveland (Annual Meeting); in 1953: March 8-11, Biloxi, Miss.; April 26-29, Toronto, Canada, joint meeting with Chemical Institute of Canada; Dec. 13-16, St. Louis (Annual Meeting).

Instrument Society

Instrument Society of America has scheduled meetings as follows: 1952, September 8-12, Cleveland; 1953, September 21-25, Chicago; 1954, September 8-21, Philadelphia; 1955, September 12-16, Detroit; 1956, September 10-14, Los Angeles.

Requests for lists of literature available from Central Office NACE will be answered promptly.

Requests for copies of Corrosion addressed to Central Office, Houston are filled (except when issues are exhausted) at the rate of 50 cents a copy for association members and 75 cents a copy for non-members.

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NACE now has over 3000 members.

Positions Available

Chemical Engineer to work on corrosion problems for major Texas pipe line company. Experience helpful but not required. Should have graduated from college in recent years. Write CORROSION, Box 52-2.

BOOK REVIEWS

New Metallizing Handbook. 250 pages. Metallizing Engineering Co., Inc., Long Island City, N. Y. Per Copy $3. Illustrated with diagrams and charts, the book covers technical and practical aspects of the metallizing process. Various methods of surface preparation, and the application of sprayed metals for machine elements, corrosion resistance and many special production jobs are explained. The book is for sale postpaid in the United States and Great Britain only.

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Punched Cards—Their Applications to Science and Industry. Edited by Robert S. Casey and James W. Perry. 506 pages, 6 x 9 inches, cloth. Reinhold Publishing Corp., 330 West 42nd St., New York, N. Y. Per Copy. $10.00 The editors assume readers are unacquainted with punch cards and their uses and proceed from the simple to the application of sprayed metals for and author indices are included. Illustrated with diagrams and charts, uses is made easy by the inclusion of specific case histories giving details of working files using punched cards.

Part III is devoted to general and fundamental considerations including suggestions on coding, mathematical analysis of coding systems, and expositions of various problems related to indexing, classification systems, transcription problems and other factors.

Part IV is devoted to an estimation of the future possibilities of punched cards.

A bibliography of uses and subject and author indices are included.

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Mathematics for Engineers. By Raymond W. Dull and Richard Dull. 822 pages, 5½ x 8 inches, cloth binding. The McGraw-Hill Book Company, Inc., 330 West 42nd St., New York 18, N. Y. Per Copy............$7.50 This is a revision of the book by Raymond W. Dull, revised and edited by Richard Dull. The third edition is a major revision including new material. The chapter on infinite series has been augmented, material on the multiplication of determinants has been added to the chapter on determinants and considerable space has been given to trigonometric functions. A discussion of complex vectors with regard to periodic functions has been included and a graphical analysis of hyperbolic functions added.

A chapter, illustrated with examples, has been added on differential equations. The final chapter is devoted to a discussion on dimensional analysis and it includes a discussion of the Buckingham *pi* theorem and its application to second order differential equations.

This book is intended primarily for engineers, providing a quick and convenient reference.

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Hydrogen Embrittlement of Steel. Review of the literature by R. W. Buzzard and H. E. Cleaves. 29 pages. Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. Per Copy..........20c Classifying defects according to a probable source of hydrogen in the metal, the paper discusses defects that may be induced by hydrogen retained after solidification of molten steel, introduced into the steel at elevated temperature, or acquired by the steel during chemical or electrochemical treatments. It contains a brief review of available information on the chemistry of hydrogen-iron system and on the effect of hydrogen on the structure and properties of iron. The selected bibliography lists 1191 items published during the last century and a half.

Style Changes Made In Abstract Section

Changes in style and arrangement of abstracts published in the Corrosion Abstract Section beginning with the January, 1951 issue of CORROSION are as follows:

1. The NACE Abstract Filing Index, June 1951 Revision is being used as a guide to topical arrangement.

2. Numbers designating topics which appear at the top of each abstract are now listed in three positions. This change is made because of the development of the NACE Abstract Filing Index which provides for sorting abstract cards through the use of a system of random numbers assigned to third subdivision topics in the index. The third numbers in the groups have no significance so far as the arrangement of abstracts published in Corrosion is concerned, because the abstracts published in Corrosion will not be subdivided past the second position. (The June, 1951 Revision of the NACE Abstract Filing Index was published as part of the *Index to Technical Material Published in Corrosion in 1951* in the December, 1951 issue. A further description of the filing index may be found in the same issue in an article by Dr. Ivy M. Parker, editor of Corrosion.) Some abstracts in early issues will have two numbers only, however.

3. Another change will be the use of the numbers associated with first and second subdivision topics as prefixes to the headings used within the Corrosion Abstracts section.

4. The style of abreviations for names of periodicals used by Chemical Abstracts will be used in the abstracts published in Corrosion effective with the January issue. A few exceptions included in abstracts set in type before the first of the year and carried over into January will be found.

AIChE Starts Inquiry Into Bubble Plates

A research project to investigate the efficiency of bubble plates used in distillation towers in chemical, petroleum and process industries is being planned by the American Institute of Chemical Engineers, as a result of a progress report prepared by Walter E. Lobo, chairman of the research committee of the institute and director of the chemical engineering division of M. W. Kellogg Company. Three universities have been recommended to carry out phases of the program on the effect of tray design and system properties on tray efficiency in both fractionation and absorption.

Copy of Polish Technical Magazine Is Received

"Prace Glownego Instytutu Metalurgii (Abbreviated Prace GIMet) a publish of the Polish Institute of metallurgy is the new title of a publication "Prace GIMO" which has been issued since 1949 at Gliwice. Volume numeration will be preserved in continuation of the previous publication, volume 3 being the one published in 1951. Six numbers are scheduled for bi-monthly publication during 1951.

No. 1 of Volume 3 contains articles on slag control in open hearth furnaces, effect of heat treatment on rate of corrosion cracking of steel in ammonium nitrate solution, testing efficacy of various methods of cleaning steel surfaces of mineral oil and others. Abstracts in English of the articles are included. The text is in Polish.

AIChE Officers for 1952 Are Elected

The following officers of the American Institute of Chemical Engineers for 1952 have been announced: William L. Burt, vice-president in charge of manufacturing of the B. F. Goodrich Chemical Company, Cleveland, has been elected president. William T. Nichols, director of the general engineering department of Monsanto Chemical Company was named vice-president and Stephen L. Tyler and C. R. DeLong, both of New York City, were reelected executive secretary and treasurer respectively.

Five directors named were William T. Dixon, J. Henry Rushton, Philip H. Groggins, J. C. Elgin and Arthur K. Doolittle.

Awards for Teaching Scheduled by ASM

American Society for Metals has set aside $6000 annually as awards to teachers of metallurgy in any school in the United States or Canada. Three awards of $2000 each will go to those teachers whose performance and influence on general progress of the profession are judged best.

Judging of the candidates applications and particulars will be carried out by a special committee appointed by the board of trustees of American Society for Metals.

Corrosion Testing Reports

Two publications relating to the work under way at the Harbor Island, North Carolina corrosion research establishment operated by The International Nickel Co., Inc., have been issued. Report on Specimens Removed from Sea Water Tests at Harbor Island, May 1951, is a technical report data in which are restricted. Record of Discussions at Sea Horse Institute Informal Conference June 1950 is a transcript of the proceedings at that year's meeting of the institute. The data are restricted also.

Corrosion Problems

E. A. TICE, Editor

Corrosion Engineering Section, The International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.

Submit questions and answers for this column in duplicate to the editor. All questions become property of NACE. Questions and Answers may or may not be published under this heading, and may at discretion, be answered by mail directly. Answers to questions are solicited. Authors of questions will remain anonymous to readers while authors of answers may remain anonymous if they request it.

QUESTION:

What is to be the future of this column?

ANSWER:

This is your column and its future depends on your contributions. If reader's interest can be measured by the contributions received during the last year, the editor is forced to reach the conclusion that the members of NACE apparently have little or no interest.

It is an easy matter to submit a question, and a few of you have taken the time to do this. But answers! It's like pulling teeth! Wisdom teeth, at that.

Early last year the editor solicited the aid of the "Corrosion Correspondents" to persuade "Corrosion" readers to submit answers to the many questions which had not yet received answers. A few of you supplied answers, and we were able to print a reasonably interesting column up through last September. But since then the editor's mail box has been collecting nothing but dust!

Perhaps we need to survey the membership to determine what is to be the future of this column. Will you please fill out the blank below and return it to the editor. No box tops or stamps need be enclosed. There will be a special reward for the first 500,000 replies, and the survey results will be published in an early issue.

It's up to you in fifty two.

The Editor

Scheduled Technical Meetings Are Listed

The following meetings of possible interest to corrosion workers have been scheduled:

January 31-February 1—American Society for Metals Midwinter Technical Meeting, William Penn Hotel, Pittsburgh. Papers will bear on researches into titanium and titanium alloys, embrittlement of iron and steel and high temperatures and oxidation, non-ferrous metallurgy and transformation and grain size.

February 7-8—Instrument Society of America, regional meeting on power plant instrumentation at Hotel Statler, New York.

March 3-7—American Society for Testing Materials Spring Meeting and Committee Week. Symposium on testing metal powders and metal powder products. Hotel Statler, Cleveland, Ohio.

March 22-April 6—Chicago International Trade Fair, Navy Pier.

June 23-27—ASTM Annual Meeting, Fiftieth Anniversary. Exhibit of Testing Apparatus and Laboratory Supplies and Photographic Exhibit. Hotels Statler and New Yorker, New York City.

September 9-13—Seventh National Chemical Exposition, sponsored by Chicago Section, American Chemical Society.

Walker Award Given

Richard H. Wilhelm, professor of chemical engineering at Princeton University received the William H. Walker Award of the American Institute of Chemical Engineers at Atlantic City, N. Y. December 4 as recognition of his achievement in chemical engineering. He is sixteenth recipient of the honor.

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The annual index to technical material published in Corrosion, appearing in the December issue, consists of a topical cross-referenced tabular index with author index and a tabular topical index to corrosion abstracts.

Return to:

E. A. Tice
Editor, Corrosion Problems
International Nickel Company
67 Wall Street
New York 5, N. Y.

1. Shall the "Corrosion Problems" column of "Corrosion" magazine be continued? _____

2. Have any of the questions and answers been helpful to you in your field of activity? Yes_____   No_____

3. Will you promise to review the questions submitted during the last year and prepare an answer for at least one? Yes_____
No_____

4. Same for 1952? Yes_____   No_____

_____

Signature, if you wish

NACE

New Members and Changes of Address

• This list is published principally for use by NACE Regional and Sectional officers in keeping their mailing lists up to date.

NEW MEMBERS

(Additions and Changes Through
Nov. 27, 1951)

GEORGIA

McCAULEY, GEORGE M., 1211 Fairview Road, N. E., Atlanta, Georgia.

LOUISIANA

WILLIAMS, ROBERT W., Esso Standard Oil Co., La. Div., P. O. Box 551, Baton Rouge, Louisiana.

OHIO

HUSCHER, JOSEPH L., American Agile Corp., 5806 Hough Avenue, Cleveland 3, Ohio.

OKLAHOMA

BRAND, JOHN W., Midwestern Engine & Equipment Co., Inc., 105 North Boulder, Tulsa, Oklahoma.

BROWN, ROBERT G., The Texas Co., Producing Dept. P. O. Box 2420, Tulsa, Oklahoma.

PENNSYLVANIA

HUITT, TROY L., H. C. Price Company, P. O. Box 6120, Philadelphia 15, Pennsylvania.

TEXAS

HALFF, ALBERT H., 6617 Snider Plaza, Dallas 5, Texas.

HARDAWAY, REX L., Taylor Refining Co., P. O. Box 4067, Corpus Christi, Texas.

MATTHEWS, JAMES C., 7360 Fairway, Houston, Texas.

MORROW, HAL PAT, Aluminum Company of America, 301 Thomas Building, Dallas, Texas.

FOREIGN

GEERLINGS, DR. IR H. G., Koninklijke/Shell Laboratorium, Amsterdam, Badhuisweg 3, Amsterdam, Holland.

CHANGES OF ADDRESS

(Old Address Follows New in Parenthesis)

CALIFORNIA

ZIMA, ALBERT G., The International Nickel Co., Inc., Petr. Bldg., 714 W. Olympic Blvd., Los Angeles 15, California. (538.)

COLORADO

TAYLOR, ROBERT W., Standard Pipeprotection, Inc., 2956 South Fairfax, Denver, Colorado. (2380 Birch Street.)

CONNECTICUT

BROWN, HARRY F., 38 Avon Street, New Haven, Conn. (New York New Haven & Hartford RR, Railroad Station.)

RICE, GERALD B., 367 Granfield Ave., Bridgeport 8, Conn. (The Bassick Company, 287 Howard Avenue.)

ILLINOIS

BOONE, HAROLD C., Peoples Gas Light & Coke Co., 1017 Richmond St., Joliet, Illinois. (The Texas Pipe Line Company.)

TERRILL, J. MARK, 1520 No. Halstead, Chicago 22, Ill. (Halsted.)

INDIANA

MEAD, WILLIAM J., 1048 Evans Street, Elkhart, Indiana. (113 Longview Street, Hutton Park, West Orange, New Jersey.)

KANSAS

GOODELL, ROBERT E., % C. N. Goodell, P. O. Box 627, Augusta, Kansas. (Phillips Petroleum Co., Adams Bldg., Bartlesville, Oklahoma.)

KENTUCKY

AKERS, J. R., Reynolds Metals Company, 2500 S. 3rd Street, Louisville 1, Kentucky. (Angus N. McDonald.)

LOUISIANA

ADAMS, LEE A., Plastivent of America, Inc., P. O. Box 105, Westwego, Louisiana. (Products Research Service, Inc., 521 Avenue F, Westwego, La.)

MONTANA

KNAPP, FREDERICK F., Western Apts. #601, 429 N. 33rd, Billings, Montana. (% Pipeline & Prod. Dept., N. M. D. U. Co., Glendive, Montana.)

NEW JERSEY

HIGGINS, EDWARD J., 334 North Chesnut St., Westfield, New Jersey. (76 Halsted St., East Orange, New Jersey.)

NELSON, H. LLOYD, United States Pipe & Foundry Co., Burlington, New Jersey. (United Concrete Pipe Corp., P. O. Box 425, Baldwin Park, California.)

NEW YORK

BAKER, RALPH D., % R. P. Bates, National Lead Co., 105 York St., Brooklyn, New York. (1925 Park Place, Dayton 6, Ohio.)

BANKS, J. A. DAVIS, American Hard Rubber Co., 93 Worth Street, New York 13, N. Y. (11 Mercer Street.)

BOLTZ, DAVID C., Metallizing Engineering Co., Inc., 38-14 30th Street, Long Island City, N. Y. (Long Island, New York.)

McLAREN, FRANCIS D., CONSOLIDATED GAS & SERVICE CO., 1819 Le Moyne Ave., Syracuse 11, N. Y. (327 South La-Salle, Chicago, Illinois.)

SATZ, LEO H., General Electric Co., Works Lab. Bldg., 37-260, Schenectady, New York. (4-129.)

SMITH, JAMES, Lithcote Corporation, 36 West 44th St., New York 18, New York. (Lithgon.)

STEVENS, CHAPIN E., GDC—Antara Products, 435 Hudson St., New York 14, New York. (General Aniline & Film Corp., 22 Center Square, Easton, Pennsylvania.)

VANDERPOOL, HOWARD, Metallizing Engineering Co., 38-14 30th St., Long Island City, New York. (1039 State Street, Bridgeport 5, Conn.)

OHIO

CAPAUL, R. W., Glass Fibers Inc., P. O. Box 973, Toledo 2, Ohio. (1810 Madison Avenue.)

SLOUGH, RALPH M., The Ohio Oil Company, P. O. Box 120, Findlay, Ohio. (539 S. Main St.)

ZANGE, MAX, 729 Park Avenue, Terrace Park, Ohio. (% James N. Dugan, 2538 Hackberry St., Cincinnati, Ohio.)

OKLAHOMA

BRADY, HUGH A., 5739 E. 7th Street, Tulsa, Okla. (Gulf Refg. Co., Tulsa Pipe Line Div., P. O. Box 661, Tulsa 2, Oklahoma.)

SMITH, REX L., Mgr., Pipe Line Dept., Skelly Oil Company, P. O. Box 1650, Tulsa, Oklahoma. (Asst., & Crude Oil Purch. Dept.)

STILGENBAUER, N. T., Hillco, Inc., P. O. Box 5006, Tulsa, Oklahoma. (4038.)

PENNSYLVANIA

DEBORD, GEORGE E., Gulf Research & Development Co., P. O. Box 2038, Pittsburgh, Pa. (1318 Wolf St., Galena Park, Texas.)

HUTCHINSON, GILBERT E., Rem-Cru Titanium, Inc., Midland, Pennsylvania. (Remington Arms Co., Inc., 939 Barnum Avenue, Bridgeport, Connecticut.)

WALTERS, WALLY Z., 223 Beaver Road, Edgeworth, Sewickley P. O., Pennsylvania. (2912 Woodside Place, Cincinnati, Ohio.)

TEXAS

GREGORY, MILTON W., 417 Parkhurst Drive, Dallas, Texas. (9315 San Fernando Way, Dallas, Texas.)

GROUNDS, LEO R., 4620 Laurel, Bellaire, Texas. (Tretolite Company, P. O. Box 2546, Houston, Texas.)

JARED, JOHN B., JR., American Petroleum Co., Petroleum Bldg., Houston 2, Texas. (John S. J. Bell.)

KLEIN, MEYER, 2116 Barbee St., Houston 4, Texas. (3511 Arbor St., Houston 4, Texas.)

KRCH, MILFORD F., Route 5, Box 523, Beaumont, Texas.

LOMAX, O. Q., Pres., Humble Pipe Line Company, 1216 Main Street, Houston 2, Texas. (Vice-Pres.)

MONTAGUE, DONALD E., 5722 Southwind Ave., Houston 21, Texas. (808 Sul Ross Avenue.)

KENTUCKY

PERKINS, C. L., El Paso Natural Gas Co., P. O. Box 1492, El Paso, Texas. (Tenth Floor, Bassett Tower.)

RAY, EDWARD B., Republic Natural Gas Co., P. O. Box 195, Midland, Texas. (1644)

THOMPSON, ROY T., Tretolite Company, P. O. Box 2546, Houston 1, Texas. (1210 Cheyenne, Tulsa 5, Oklahoma.)

TYLER, JOHN C., JR., P. O. Box 644, La Porte, Texas. (Gulf States Asphalt Co., 300 Christy Place, South Houston, Texas.)

WATSON, ROGER D., 346 McCune, El Paso, Texas. (7658 Barton Road.)

WINTLE, JAMES V., JR., Texas Pacific Coal & Oil Co., Sundown, Texas. (Midland, Texas.)

FOREIGN

FLORES, ING. LEOPOLDO NETTEL, Petroleos Mexicanos, Refineria De C. Madero, C./ Madero, Tamps., Mexico. (Nettal.)

SEARCY, JOHN E., JR., Creole Petroleum Corp., Cabimas, Zulia, Venezuela, S. A. (United Gas Pipe Line Co., P. O. Box 1407, Shreveport, Louisiana.)

SPECTOR, DOV, 18, Mikve Israel St., Tel-Aviv, Israel. (Schapira Tyroler & Co., Electrical Engineers.)

Annual Memorial Lecture Will Honor A. W. Gillett

An annual memorial lecture honoring H. W. Gillett, first director of Batelle Memorial Institute, Columbus, Ohio and an active worker for many years in the American Society for Testing Materials has been established by ASTM in co-operation with Batelle. It will be delivered annually at an ASTM meeting, the first to be given June 23 at the society's 50th anniversary meeting at New York City.

The lecture will pertain to the development, testing evaluation and application of metals and the lecturer will be selected by a committee appointed by the ASTM board of directors. Further provisions in the agreement between ASTM and Batelle provide for an honorarium and publication of the lecture.

Dr. Gillett, who died in March 1950, was an active member in many technical and scientific groups.

Identification Methods Given for Nickel Scrap

Identification of nickel-containing scrap is facilitated by three procedures recommended by The International Nickel Co., in an article called "First Aids in Scrap Salvage." By the use of five reagents and a magnet and small medicine dropper rapid identification of nickel containing alloys can be made. The article will appear in Inco Magazine.

Copies of a pamphlet, "Rapid Identification of Some Metals and Alloys," published by the Development and Research Division of the company, are available from the offices on request. This gives tests for spot identification of ferrous and non-ferrous metals and alloys.

•

The inter-Society Corrosion Committee provides a means whereby organizations engaged in corrosion research may correlate their efforts to avoid duplication of effort.

•

Technical Committees of NACE are formed when sufficient interest is evidenced and after approval by the chairman of the Technical Practices Committee and the association's governing board.

Very Few Booths Left Unassigned For Galveston Conference Exhibit March 10-14

Only 17 booths remained unassigned December 17 for the Eighth Annual Conference and Exhibition of NACE at Galveston, Texas, March 10-14. There is reason to believe all but one or two may have been assigned by the time this issue of Corrosion is distributed, according to Jack Harris, exhibition chairman.

This year's exhibit will continue the trend of the past several years in NACE exhibits, with a widening variety of corrosion control materials and methods displayed. This diversification reflects the interests of the membership.

The accompanying diagram of booth arrangements shows how the exhibits committee has laid out the booths so traffic will pass all of them enroute to the principal meeting room on the gulf end of the Galveston Municipal Pier.

Following is a partial list of exhibitors for the 1952 conference:

Acme Fisher of Texas
Aluminum Company of America
Amercoat Corporation
Anderson-Prichard Oil Corp.
Apex Smelting Company
Arco Rubber Processors
The Barrett Division,
   Allied Chemical & Dye Corp.
Bauer & Black,
   Polyken Industrial Tape Div.
Brance-Krachy Co., Inc.
Cameron Iron Works, Inc.
Cathodic Protection Service
Centriline Corp.
The Chemical Corporation
Crutcher-Rolfs-Cummings, Inc.
Dearborn Chemical Co.
Dow Chemical Company
Dowell Incorporated
Dresser Manufacturing Div.
   Dresser Industries, Inc.
Duriron Company
Electro Rust-Proofing Corp.
Federated Metals Division,
   American Smelting & Ref. Co.
Good-All Electric Mfg. Co.
Harco Corp.
Haveg Corp.
Haynes-Stellite Company
Hill, Hubbell & Company
Hills-McCanna Company
Insul-Mastic Corp. of America
International Nickel Co., Inc.
Johns-Manville Sales Corp.
Koppers Company, Inc.
Lebanon Steel Foundry
Magnaflux Corp.
Metallizing Engineering Co., Inc.
Middle West Coating & Supply
Midwest Pipeline Service Company
Midwestern Engine & Equip. Co., Inc.
Monsanto Chemical Company
Napko Paint & Varnish Works
Natasco Company
National Carbon Division,
   Union Carbide & Carbon Corp.
National Lead Company
Nelson Electric Mfg. Co.
Nukem Products Corp.
Owens-Corning Fiberglas Corp.
Permolite, Inc.
Petrolite Corp.
   Tretolite Division

Philip Carey Mfg. Co.
Pipeline Coating & Eng. Co.
Pipe Line Service Corp.
Pittsburgh Coke & Chemical Co.
Plastic Engineering & Sales Co.
Reily Tar & Chemical Corp.
Royston Laboratories, Inc.
Rust-Oleum Corp.
Service Engineers, Inc.
Nowery J. Smith Co.
Socony Paint Products Co.
Standard Magnesium Corp.
Standard Pipeprotection Inc.
D. E. Stearns Company
Tapecoat Company
Tennessee Eastman Company
Texas Tubing & Supply Co., Inc.
Tinker & Rasor
Tri-Clover Machine Co.
Tube-Kote, Inc.
T. D. Williamson Inc.
U. S. Stoneware Co.

Alquist Becomes New TP-13 Chairman

F. N. Alquist of The Dow Chemical Company, Midland, Mich., has assumed chairmanship of Technical Practices Committee 13—Annual Losses Due to Corrosion.

Dr. Alquist, currently chairman of the NACE Editorial Review Committee, said his company has problems in corrosion costs and he has interests in this field.

Report of Armour Foundation Is Issued

The Armour Research Foundation of Illinois Institute of Technology, Chicago has issued its 1951 report in which has been reported brief descriptions of research in progress, sponsors and organizational information.

Significant to corrosion workers is research reported and that the foundation has installed a corrosion laboratory.

The foundation concluded research into silica deposition on turbine blades, discovering valuable knowledge of the deposition mechanism and preventive measures. The metals research department also studied stress corrosion, the flow of molten metal, seam welding and silicon alloys.

Projects in jet engine exhaust, metal-ceramic combinations, residual stress and others are described briefly. In the chemistry and chemical engineering division work is being done to discover substitutes for sulfonate lubricating oil inhibitors, on flame spraying of polyethylene, on lacquer finishes, and a survey of corrosion problems in pulp and paper manufacturing is under way. Research is being conducted to develop a material for operation at high temperatures with dimensional stability and resistance to strong corrosive effects, and another project involves a study of stress corrosion of aircraft alloys.
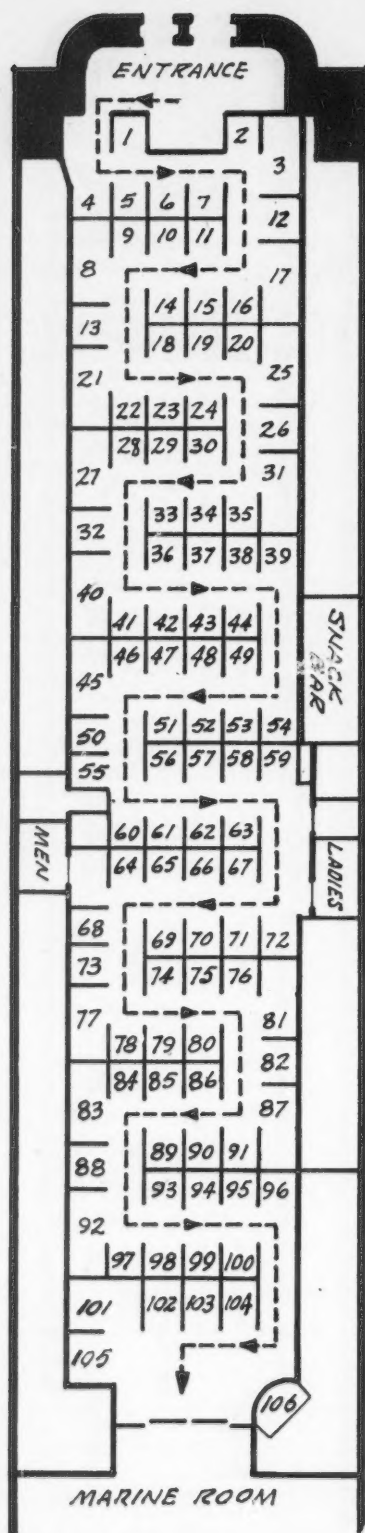
GALVESTON MUNICIPAL PIER

Showing arrangement of booths for Eighth Annual NACE Exhibit.

NEW PRODUCTS — Materials — Service — Literature

Vacuum Equipment, including dehydrators, shelf dryers, freeze dryers, impregnators, extraction and solvent recovery apparatus and vacuum pumps are described in Catalog No. 715, "Complete Vacuum Processing Systems," available from F. J. Stokes Machine Co., 5500 Tabor Rd., Philadelphia 20, Pa.

•

Odorless Industrial Paints, which have no odor during application but have qualities required by food processing industries such as resistance to steam cleaning, dampness, butter fat and greases are available from Wilbur & Williams Co., 130 Lincoln St., Brighton 35, Mass. Odorless Dampcoat enamel is available in gloss, eggshell or flat finish.

•

High Temperature ceramic coatings of a special ceramic less than .001-inch thick increase the resistance of jet engine component subjected to the corrosive and erosive blast of 2000 degree F exhaust gases. The high temperature coating was developed by William Harrison of the Enamel Metals Division of the National Bureau of Standards and is being applied to aircraft engine parts by Bettinger Corp., Waltham, Mass. The company forsees an extended market for application of the material to commercial equipment subject to corrosives.

•

Ortho-Nitrobiphenyl, a plasticizer and chemical intermediate manufactured by Monsanto Chemical Co., Organic Chemicals Division, 1700 S. Second St., St. Louis 4, Mo., is described in a technical report, Monsanto Technical Bulletin No. O-78. The material, a general purpose plasticizer for most types of plastic, lacquer and adhesive compositions, is compatible with a wide variety of resins including cellulose esters and ethers, polyvinyl chloride and its copolymers, polyvinyl formal, polyvinyl butyral, acetate, alcohol, polystyrene, rosin, rosin esters, modified rosin esters modified phenolic, oil soluble phenolic and alkyd resins and vegetable oils.

•

Red Lead Paint Formulations Red Lead Technical Letter No. 6 issued by Lead Industries Association, 420 Lexington Ave., New York 17, N. Y., gives a formula index and table of general properties, red lead paint formulations, and a description of red lead primers for vinyl systems, with two formulas conforming to military specifications.

•

Tube-Turns, Inc., Louisville 1, Kentucky, is producing an SF (Scale Free) welding coupling designed to permit welding pipe without causing scale, burn-through or icycles. Available in 1-1/14-inch through 12 inches they are made in carbon, stainless steels, aluminum and other metals and alloys.

•

Star Stainless Screw Company, 190 Union Ave., Paterson 2, N. J., carries in stock small stainless steel screws in Class 3; 0/80-1/72-2/64 up to 1-inch with AN drilled heads.

Gries Reproducer Corp., 780 East 133 Street, New York 54, N. Y., die casts very small zinc alloy tubular and semitubular rivets from 1/16-inch to 9/64-inch and lengths up to 6/16-inch with oval or flat countersunk heads.

•

Schleicher & Schuell Company, Keene, New Hampshire, offers a 36-page catalog of quantitative and qualitative filter papers and accessories for their use. The catalog also contains a 12-page reference table for filtrations in methods of inorganic analysis as well as information on literature references of government publications dealing with analytical filtering and methods of testing filter papers.

•

Polyken Standard Industrial Classification Manual, a handbook of Polyken industrial tape applications classified by industry, may be secured on request by legitimate users of industrial tape on request to Polyken wholesalers, or by writing to Section P2, Polyken Industrial Tape, Dept. of Bauer & Black, 222 West Adams St., Chicago 6. The 80-page book lists about 1500 distinct uses for industrial tape.

•

National Carbon and Graphite and Karbate Impervious Carbon and Graphite products are described in a new 20-page catalog section available from National Carbon Company, a Division of Union Carbide and Carbon Corp., 30 East 42nd St., New York 17, N. Y. Information is given on sizes and physical characteristics of each product. Catalog is numbered Section S-5005.

•

Stainless Steel conveyor belts are being used at the Port Neches, Texas synthetic rubber plant operated for the Office of Rubber Reserve by United States Rubber Company's Naugatuck Chemical Division. They are used to convey wet crude rubber through drying ovens.

•

Ferrolum, steel with a lead coating bonded to it and Cupralum, copper with a lead coating bonded to it are two new products of Knapp Mills, Inc., 23-15 Borden Ave., Long Island City, N. Y., which offers for interested potential users an illustrated 22-page booklet about the materials. The new coated materials are suggested for use in handling sulfuric acid and in other corrosive environments where the resistance of lead is important.

•

Duriron Company, Dayton 1, Ohio, has issued Bulletin P/1 giving detailed information about its latest Series R Durcopumps. They are fabricated of a complete range of corrosion resistant alloys. This heavy duty pump is designed for severe corrosive service and has numerous features intended to prolong its useful life and increase its efficiency.

•

Alco Products Review, an external house organ published by Alco Products Division of American Locomotive Company, Schenectady 5, N. Y., gives information about the division's products

including heat exchangers, pressure vessels and pipe. Copies may be obtained from any of the company's sales offices.

•

Shenango-Penn Mold Company, Centrifugal Castings Division, Dover, Ohio, producer of non-ferrous, Meehanite, Ni-Resist and special iron alloy centrifugal castings will send on request copies of its Bulletins No. 150 and 151. Advantages of the company's products and facilities for precision production are explained.

•

RCA Special Metal Detector is designed for the inspection of thin sections of non-metallic material in which it will detect both non-ferrous and ferrous metal if present. Particles as small as .039-inch in diameter are located. It is described in catalog E-61 available from Eriez Manufacturing Co., Erie, Pa.

•

Canadian Equipment Sales and Service Company of Edmonton, Alberta and Toronto, Ontario has been named exclusive agent in Canada by T. D. Williamson, Inc., Tulsa, Oklahoma.

•

Boltaron 6200 series rigid vinyl plastic tubing, pipes, rods, sheets, blocks and molding compounds will be distributed by H. N. Hartwell & Son, Inc., Boston. Based on Geon 404, the high molecular weight vinyl resin can be processed without addition of plasticizers and gives all properties of straight polyvinyl chloride.

•

Plantation Pipe Line Company began operating December 4 a new 700-mile parallel trunk pipe line to carry refined petroleum products to six Southeastern states. It is a common carrier, transporting petroleum products for 14 oil marketing companies, and linking Louisiana and Texas refineries with inland markets. The 1967-mile system has a delivery capacity of 10 million gallons daily.

•

Cathodic Protection Service, Sales Division, Houston has been named an exclusive agent to handle its line of cathodic protection rectifiers by Good-All Electric Manufacturing Company, Ogallala, Neb. Cathodic Protection Service also handles Dow Metal magnesium, National Carbon Company graphite anodes and backfills; Homco and Barada and Page backfills, F. H. Maloney Company insulating materials, Rubicon potentiometers, Fisher M-Scope pipe and cable locators, Agra meters, Associated Research resistivity meters, CPS service meters, electrodes, coke breeze, and Holloway shunts.

•

Technical papers presented at national meetings of NACE are usually published in Corrosion after review and approval by the association's editorial review committee and the editor of Corrosion.

•

Technical articles published in Corrosion are reprinted only on special order. Prices on reprints in quantities of 50 or more will be sent on request.

20

PERSONALS

Julius H. Hill has been named Southern regional manager by Metalizing Engineering Co., Inc., with offices at New Orleans.

A. C. Polk, Jr., has been made general manager of Dowell Incorporated, Tulsa. A Houstonian, Polk before promotion to assistant manager in 1948 was Houston District manager, and previously had been at Levelland, Texas, and Shreveport, and Lafayette, La.

James S. Anderson, who has been on leave in Washington serving as chief of the Tubing Section of the Iron and Steel Division of the Industry Operations Bureau of the National Production Authority since April, 1951, has returned to his post of assistant general sales manager of Babcock & Wilcox Company.

Dr. Walther Mathesius, who retired as president of Geneva Steel Company December 1, has become a consultant of Freyn Engineering Department of Koppers Company, Inc.

W. B. Anderson, formerly manager of Westinghouse Electric Corporation's aviation gas turbine division has been appointed assistant to the executive vice-president, defense products. Replacing Mr. Anderson will be Frank L. Snyder, formerly manager of the transformer division.

G. P. Connell, professor and head of the Department of Chemical Engineering of Lawrence Institute of Technology, has joined the corrosion engineering staff of the Hinchman Corp. He is a graduate of McGill University, Montreal.

Mel Judah, engineer on the Central Office staff of NACE resigned December 21 to return to active duty with the United States Navy. He will report to a heavy cruiser in the Pacific fleet early in January. Mr. Judah, a Pacific veteran of World War II has been active in the Naval reserve, serving as senior instructor and as a personnel officer in the Houston unit during the past three years.

Since joining the association's staff in 1948 he has assisted technical committees in the reproduction and distribution of reports and the abstract committee in its publication of the 1946-47 Bibliographic Survey of Corrosion and in the initiation of the Abstract Punched Card Service. As an active member he has been arrangements chairman for Houston Section for the past two years.

He attended annual conferences at Cincinnati, St. Louis and New York; Permian Basin Inspection Tours of 1948, 1949 and 1951; the Short Course in Corrosion at Austin in 1949 and several South Central Region and section meetings.

During the nearly four years he was with the association it has more than doubled in size and Central Office staff has increased from five to fourteen to serve the growing activities of the association. Mr. Judah expressed his appreciation for the friendly cooperation of the many members with whom he has had the pleasure of working. Emphasizing the excellent spirit of the membership and the efficient organization of Central Office, Mr. Judah voiced the belief the association will certainly continue to grow and be of still greater service to its members. He hopes circumstances will permit his return to more active participation in association affairs in the near future.

Dr. A. Lloyd Taylor has been named director of research of MacDiarmid Western, Inc., Ferndale, Mich., where he will work in the field of industrial detergents. He formerly was director of the department of chemistry of Pease Laboratories, New York and director of research for Oakite Products, Inc. as well as research supervisor for Wyandotte Chemicals Corp.

Dr. Robert J. Anderson, formerly with Light Metals Division, National Production Authority, Washington, D. C. has joined Southwest Research Institute, San Antonio, Texas.

Dr. Henry C. Rosenberg has joined the research staff of Dearborn Chemical Company, Ltd., Toronto.

R. P. "Pipe" Bender, formerly with Tennessee Gas Transmission Company has been made manager of the Fort Worth office of Plastic Engineering and Sales Corp. He formerly was with Mayse Bros., Houston, and operated the Southern Pipe Coating Company. W. C. "Bill" Lyons, chemical engineer formerly with Cities Service Refining Co., Lake Charles, La. has joined the staff of Pesco.

Index to CORROSION ABSTRACTS

(Breakdown of Industry groups will be found in Index to Technical Material, Corrosion, December, 1951)

* PAGINATION OF CORROSION ABSTRACTS

Two numbers appear on each page of Corrosion Abstracts. The number in the upper outer corner is for page sequence within the issue only. The number in the lower outer corner, which is followed by the letter "a," denoting "abstracts," is for the convenience of those who bind Corrosion Abstracts by volumes. Because both numbers appear on each page and because it is believed indexing by the volume serial number will be more useful, the "Index to Corrosion Abstracts" is keyed to the number in the lower outer corner of each page followed by the letter "a."

2. TESTING

2.4 Instrumentation

2.4.3

Industrial Inspection Methods. Ed. 2. LENO C. MICHELON. 566 pages. 1950. Harper & Brothers, New York.

Deals with the growth in techniques, standardization, new devices and statistical methods since 1941. Emphasizes standard terminology and methods. Presents step-by-step description of good inspection practice. Includes questions and problems with each chapter.—BLR.

2.4.3

Xeroradiography — A Basic Development in X-Ray Nondestructive Testing. ROBERT C. McMASTER AND ROLAND M. SCHAFFERT. *Non-Destructive Testing*, 9, 11+ (1950) Summer.

Describes new rapid, low-cost, all-electric method of obtaining permanent X-ray images. It does away with film and chemical processing. There are none of the usual time delays between exposure and examination. Contrast sensitivity is better than the 2 percent required for inspection of aircraft parts. In addition, the process possesses an unusual local contract sensitivity which reveals small discontinuities clearly. Definition exceeds 200 lines to the inch. Speed exceeds that of most non-screen X-ray films.—BLR.

2.4.3

Industrial Applications of Radiography and the Inspection of Welds. L. MULLINS. *Sheet Metal Ind.*, 26, No. 270, 2193-2206 (1949).

A comprehensive review of radiog-

REPRINTS

Cathodic Protection and Pipe Lines

A Proposed Standard Method for Measuring the Electrical Resistance of Pipe Line Coatings by W. F. Rogers, B. H. Davis, Lyle Sheppard, Donald Bond, L. G. Sharpe, E. R. Allen and P. T. Miller.

Utilization of Electrically Insulated Couplings in Corrosion Control by W. F. Levert.

Mitigation of Corrosion on City Gas Distribution Systems by A. D. Simpson, Jr.

Paints and Coatings

The Effectiveness of Paint in Suppressing Galvanic Corrosion by G. W. Seagren, G. H. Young and F. L. LaQue.

Formulation of Industrial Paints by John W. Nee.

Tests, Properties of Corrosion Preventive Lubricants for Lead Sheathed Cables in Underground Ducts—A Discussion by Howard S. Phelps and Frank Kahn.

Petroleum Production and Storage

Corrosion in Condensate and in High Pressure Sweet Oil Wells by R. C. Buchan.

The Use of Ammonia in Control of Vapor Zone Corrosion of Storage Tanks by F. T. Gardner, A. T. Clothier and F. Coryell.

Miscellaneous

Causes of Corrosion in Airplanes and Methods of Prevention by N. H. Simpson.

Cathodic Protection of an Active Ship in Sea Water by K. N. Barnard and G. L. Christie.

Corrosion of 18-8 Alloy Furnace Tubes in High-Temperature Vapor Phase Cracking Service by E. Q. Camp, Cecil Phillips and Lewis Gross.

Salt Spray Testing Bibliography by Lorraine Voight.

The Cost of Corrosion to the United States by H. H. Uhlig.

Why Metals Corrode by H. H. Uhlig.

Reprints of Technical Practices Committee Reports

Report of TP-12 on Electrical Grounding Practices.

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raphy. The properties of X- and gamma-rays are discussed, and the necessary equipment is described, including the layout of a typical radiography department. The inspection of welds is dealt with in detail, including typical dispositions of the X-ray beam for various weld forms. Radiography of castings and the application of radiographic techniques to various engineering problems is included. Concludes with a discussion of the significance of radiographic evidence, and the method is considered to be a valuable inspection tool if properly applied. —MA.

2.4.3

Recent Developments in the Non-Destructive Testing of Materials by Electrical and Magnetic Methods. W. JELLINGHAUS. *Engineers' Digest*, 11, 271-275 (1950) Aug. Translated and condensed from *Stahl u. Eisen*, 70, 552-560 (1950) June 22.

Principles, improvements, advantages and disadvantages, and applications of electrical and magnetic methods of non-destructive testing are discussed, consideration also being given to oil-bath, fluorescence and thermal methods.—BLR.

---

3. CHARACTERISTIC CORROSION PHENOMENA

3.3 Biological Effects

3.3.4, 8.9.1

The Pathology of Metals: Corrosion of Steel and Alclad Parts by a Fungus. W. J. COPENHAGEN. *Metal Ind.* (England), 77, Nos. 9-10, 137 (1950) Sept. 8.

Extensive mould growths and corrosion products on aluminum and steel aircraft parts in wooden packing cases after being in transit to South Africa for two months are attributed to the use of unseasoned wood containing mould spores and inadequate ventilation. Bluish-black discolorations and a white amorphous deposit were visible on the Alclad parts (engine cowl, fuselage, main planes and rudders). The white deposit was very noticeable on these parts under Bitumastic paper fastened by adhesive tape. Here, there was less discoloration and it was confined to within a few inches of the adhesive tape. Pitting was observed beneath the white amorphous deposit and on the periphery of the spots. Tests showed that the white powder consisted of basic aluminum acetate and that the corrosion products contained acetates. The packing cases were of watertight construction and ventilated by four six-inch holes covered with wire on the floor.—ALL.

3.5 Physical and Mechanical Effects

3.5.8, 6.4.4, 4.2.1

Corrosion Resistance of Magnesium Alloy Tested. *Iron Age*, 166, 82 (1950) Nov. 16.

Outlines results of work by National Bureau of Standards on stress-corrosion resistance of 6 wrought magnesium alloys and one clad alloy in marine and inland atmospheres.—BLR.

3.5.8, 3.7.3

Fatigue Weakness of Surfaces. J. O.

ALMEN. *Product Eng.*, 21, 117-140 (1950) Nov.

Discusses shortcomings in current testing procedures and concepts that should be corrected by careful analysis and evaluation of weakness of the surfaces of materials in fatigue. Machine parts are so far removed from ideal laboratory fatigue specimens that the latter give misleading indications of serviceability. Discusses theory and practice of shot peening, peening while the material is being stressed, measurement of residual stress, prestressing, effect of removal of stress raisers, residual stress induced by mechanical operations, by thermal treatment, by case-hardening, by nitriding and by carburizing.—BLR.

3.5.8, 6.2.3

Stress-Corrosion Cracking of Mild Steel. R. N. PARKINS. *Welding J.*, 29, 458s (1950) Sept.

Discusses paper by D. Cubicciotti and William Bover (Mar. issue). Believes that conclusion of the latter that cold working of the metal acts as a preventive to stress-corrosion is not justified. Includes authors' reply.—BLR.

3.5.8

Nature of Fatigue of Metals. R. E. PETERSON. Westinghouse Res. Lab. *Mech. Eng.*, 72, No. 5, 371-375 (1950) May.

A discussion on the nature of fatigue of metals notes how the limited knowledge of the early 1800's, with regard to mechanics of materials, was entirely inadequate to explain the mysterious failures occurring due to the advent of steam-driven machinery. The metal presumably "crystallized," but it was not generally realized that repetition of loading was involved. It is also noted how the concept of an endurance limit was established. The "crystallization theory" of a century ago has been proved unsound by metallographic studies, and outstanding work is noted in more recent times with single crystals and groups of a few crystals. The mechanism of slip, in accordance with maximum resolved shear stress is mentioned, and attention is called to the common ground of plasticity and fatigue. The use of X-ray diffraction method, as well as possible use of the electron microscope, is discussed. Conditions of failure in glass and in lead at room temperature and in steel at high temperature are mentioned. It is hoped that the brief review will serve to stimulate further work in this field, and that the review and references will be helpful to those contemplating work aimed at furthering knowledge of the mechanism of failure of metals.—TDD.

3.5.8, 6.4.4

Stress-Corrosion Resistance of Wrought Magnesium Alloys. Nat. Bur. Standards. *Tech. News Bull.* 108-110, 1950 Aug.

An extensive investigation was conducted into the resistance of wrought magnesium alloys to corrosion under stress both in a marine atmosphere and an inland atmosphere. The investigation included both sheet and extruded alloys. The Sheet materials were the M1, AZ31X, AZ51X, AZ61X alloys and a clad alloy in which a core of AZ31X sheet was sandwiched between two thin layers of the M1 alloy; extrusions studied were the ZK-60, AZ61X, AZ80X, and AZ80X-HTA. Of all the materials studied, the M1-clad AZ31X-h alloy was the most resistant to stress corrosion. Among the bare alloys, the M1-h sheet and the

ZK-60 extruded material were outstanding in stress-corrosion resistance.—TDD.

3.5.3
Cavitation Produced by Ultrasonics. B. E. NOLTINGK AND E. A. NEPPIRAS. *Proc. Phys. Soc.* (London), **63**, sec. B 674-685 (1950) Sept. 1.

The problem of above type of cavitation is examined theoretically. Equations are developed which describe the motion of a gas-filled cavitation bubble in a liquid medium subjected to alternating pressure; the case of an empty cavity is also considered. Predicts that all cavitation phenomena will diminish and finally disappear as frequently is raised.—BLR.

3.5.8, 8.4.3
Drill Pipes and Tool Joints Undergo Rigid Tests for Fatigue. WILLIAM S. BACHMAN. *Drilling*, **12**, 20-21 (1950) Dec.

Discusses both ordinary fatigue and corrosion fatigue, the latter being responsible for most service failures. Results from fatigue tests on full-size, 4½-in., drill-pipe connections are given. Factors which affect fatigue strength of a drill pipe connection are also discussed, and a sample fatigue-strength problem is included to demonstrate how the higher fatigue stress values of the newer type connections have practically eliminated failures at tool joints.—BLR.

3.6 Electrochemical Effects

3.6.8
Overvoltage of Hydrogen Upon a Platinized-Platinum Electrode. MAURICE BONNEMAY AND RAOUL BUSSO. *J. Chim. Phys.*, **46**, 9/10, 455-458 (1949).

The overvoltage of hydrogen in the presence of a platinized platinum wire electrode was determined at various temperatures for various concentrations of hydrogen ions and various anions, sulfate, nitrate, and chloride ions. Using a cell comprising a platinized platinum wire cathode and a much larger plane polished platinum anode, it was found that the form of the graphs of overvoltage plotted against current are considerably influenced by the state of the metal/gas interface. Audubert's equation relating the current intensity to the activity of the ions in the neighborhood of the electrode, the coeff. of energy transfer, and the overvoltage is considered to be verified for the overvoltage of hydrogen upon a platinized platinum electrode, but use of the equation to calculate values of the coeff. of energy transfer gives results not in accord with theory.—MA.

3.6.6
Galvanic Corrosion and Its Practical Significance. G. T. COLEGATE. *Metal Treatment*, **15**, No. 56, 183-192 (1948-1949).

The electrochemical theory of corrosion is described, and the factors affecting the current flow in corrosion processes, such as resistance of electrolyte, concentration polarization, and polarization due to film formation, are discussed. The effect of environment on galvanic corrosion and the galvanic corrosion occurring with copper, aluminum, magnesium, iron, and their alloys is discussed. Methods of preventing galvanic corrosion, e.g. by painting or metallic coatings, are referred to.—MA.

3.6.1, 5.4.5
Notes on the Electrochemical Behaviour of Paint Films on Steel in Sea-Water. J. T. CRENNELL. *J. Soc. Chem. Ind.*, **69**, Supplementary Issue No. 1, S36-S38 (1950).

Experiments indicating that any inert barrier partly but imperfectly screening a steel surface (including ordinary paint films) will induce the surface to act as a cathode in sea-water. It is concluded that underwater primers should be pigmented with zinc dust rather than aluminum.—BNF.

3.6.6
The Correct Application of the Gibbs-Helmholtz Equation to Reversible Galvanic Cells in Which Several Phases Are in Equilibrium at One of the Electrodes. R. E. BARIEAU. *J. Am. Chem. Soc.*, **72**, 4023-4026 (1950) Sept.

Points out that confusion over the above has resulted from a failure to write correct reactions for cells involving several phases in equilibrium at the electrodes. The principle to be followed is stated and its application is demonstrated by developing the complete cell reaction for the Clark cell.—BLR.

3.7 Metallurgical Effects

3.7.3, 6.2.3
The Effect of Cold-Work on Steel. Section I. Effect of Carbon on the Work-Hardening Properties of Steel. Section

II. Effect of Cold-Work Upon Electrical Resistivity of Steel. Section III. An X-Ray Investigation of Internal Strains in Cold-Drawn Steels. J. H. ANDREW AND P. E. BROOKS. **Section IV. Effect of High-Speed Deformation on Steel.** J. H. ANDREW AND L. BOURNE. **Section V. An X-Ray Investigation of Structural Changes in Steel Due to Cold-Working.** D. V. WILSON. **Section VI. Effect of Cold-Work on Hydrogen in Steel.** J. H. ANDREW, U. V. BHAT, AND H. K. LLOYD. **Section VII. General Discussion.** *J. Iron Steel Inst.*, **165**, 146-184, 369-395 (1950) June, Aug.

Includes tables, graphs, micrographs, and diffraction patterns. Cold work decreases the rate of hydrogen diffusion and increases the saturation.

3.7.3, 6.4.2
Soldering of Aluminum: Avoidance of Brittlement. Aluminum Development Association. *Metallurgia*, **42**, No. 250, 131-133 (1950) Aug.

Method of soldering aluminum involving pre-treatment by abrasive or by phosphoric/nitric acid treatment followed by tinning with tin-zinc solder and finishing with tin-lead. Results of investigations showed that some aluminum alloys exhibit brittleness and cracking as a result of penetration of solder. Pure aluminum, aluminum-1 manganese and annealed aluminum-2 magnesium and aluminum-3.5 magnesium were free from this tendency; fully heat treated aluminum-1 magnesium-1 silicon and aluminum - magnesium - zinc were the most susceptible.—BNF.

3.7.3, 6.4.2
Final Report on Development of an Alloy Permitting Low Temperature Joining of High Strength Aluminum Alloys. E. H. KINELSKI. Cornell Aeronautical Laboratory, Inc., Buffalo. Report KA-497-M-4; Navy Contract NOa(s) 9935 (1949) Oct.

In the investigation of an alloy for joining high-strength aluminum alloys at low temperatures, a vibration method of soldering and a new zinc-cadmium-beryllium-copper solder were developed. Preliminary attempts were also made to braze titanium with brazing alloys for comparison with aluminum.

Solution potential measurements indicated that all aluminum solders tested would corrode in a corrosive atmosphere. When solder containing zinc was deposited on stressed 24ST aluminum strip, no cracks or intergranular penetration of solder occurred. Dip soldering with vibration gave a very poor joint.

Titanium was successfully brazed with an argon-shielded arc torch; gas-torch brazing was unsuccessful. Commercial brazing alloys gave brittle joints owing to the formation of an intermetallic compound. Pure-silver brazed joints produced tensile strengths around 50,000 psi and there was no evidence of the formation of an inter-metallic compound. Titanium brazing by means of a salt bath or hydrogen atmosphere was unsuccessful. In the salt bath, the titanium apparently reacted with absorbed gases; in hydrogen, the titanium became extremely brittle.—PDA.

3.7.3, 6.3.15
Effect of Welding on the Properties of Titanium-Carbon Alloys. E. M. MAHLA AND R. B. HITCHCOCK. *Welding J.*, **29**, 544s-551s, (1950) Nov.

The inert-gas-shielded tungsten arc process was found to be satisfactory for welding titanium-carbon alloys. 0.25 percent carbon is the maximum permissible for ductile welds in the as-welded condition. Presents bend, tensile, and corrosion-test data, as well as results of metallographic studies. Includes photomicrographs and electron micrographs, tables, and graphs.—BLR.

3.7.3
Concerning the Quality of Welds Obtained by Automatic Welding Under Winter Conditions. (In Russian.) B. I. MEDOV AND A. E. ASNIS. *Avtogennoe Delo* (Welding), **21**, 1-8 (1950) Aug.

The above was investigated for low-carbon steel of ordinary thicknesses. It was found that impact strength and brittleness under the above conditions are essentially the same as under standard conditions. Probability of formation of pores and cracks increases due to increase of rate of cooling. Conditions under which welding at freezing temperatures is permissible were determined. Experimental data are tabulated and charted.

3.7.2, 3.5.9
Heat-Resisting Steels; Influence of Alloy Additions. G. T. COLEGATE. *Metal Treatment and Drop Forging*, **17**, 93-101+ (1950) Summer.

Various types are considered briefly. Indicates effects of small additions of other elements such as strontium, niobium, cobalt and molybdenum to each type. Oxidation resistance, creep, tensile strength, yield strength, elongation, area reduction, proportional limit, and Brinell hardness are tabulated and charged.—BLR.

3.8 Miscellaneous Principles

3.8.4
The Mechanism of Redox Reactions with Oxyacids as Co-Reagents. (In German.) E. ABEL. *Helv. Chim. Acta*, **33**, 785-790 (1950) June 15.

Discusses the electron-transfer theory of redox reactions, especially the mechanism of the above type of redox reaction.—BLR.

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4. CORROSIVE ENVIRONMENTS

4.6 Water and Steam

4.6.2
Eleventh Annual Water Conference. Papers before Eng. Soc. of Western Pa., 11th Ann. Water Cong., Pittsburgh, Oct. 16-18, 1950. *Combustion*, **22**, No. 5, 55-59 (1950) Nov.

Papers include: The Dianodic Method for the Prevention of Pitting and Tuberculation by H. L. Kahler & C. George. High Pressure Boiler Feedwater Treatment, Evaporation Vs. Demineralization and Silica Removal by V. J. Calise. Evaporator Purity as Related to Station Design by R. M. Buchanan & A. A. Pace. Sampling of Steam for the Determination of Purity by B. J. Cross. An Economic Analysis of Condensate Corrosion Control Methods by T. B. Kneen & R. R. Kountz. Experimental Studies of Boiler Scale at 2500 psi by J. A. Holmes & C. Jacklin. Initial Report of Operating Data from Industrial Mixed Bed De-Ionizing Units by W. S. Morrison & A. H. Kahler. Hot Lime Treatment Followed by Sodium Zeolite by S. B. Applebaum. Evaporator Feedwater Treatment at Semaren Generating Station by J. R. Denton & R. I. Smith.

Discussions of the papers are included.—INCO.

4.6.4
Treatment of Cooling Water. S. B. APPLEBAUM. Cochrane Corp. *Combustion*, **22**, No. 5, 41-48 (1950) Nov.

Descriptions of the once-through and the recirculating systems, with comments on their adaptability to given conditions. The text takes up deposits and their treatment, comparison of different treatments, capacity calculations and concludes with typical cases involving an acid-treatment plant and lime-acid treatment.—INCO.

4.6.2, 7.6.4
Magnetic Iron Oxide Scale in a 420 PSI Boiler. JOHN H. MOORE. *Proc. Midwest Power Conference*, **12**, 122-132 (1950).

Considers source and character of the raw water at Hoot Lake (Minn.) station. Describes appearance of magnetic iron oxide, condition of boiler at several inspection intervals, and remedies applied. Results are tabulated and discussed.—BLR.

4.6.11, 7.6.9, 8.4.3
Observations on Protecting Steel Structures Exposed to Sea Water. B. B. MORTON, Paper, ASME Conf., New Orleans, July 24-28, 1950. *Oil Gas J.*, **49**, No. 22, 123 (1950) Oct. 15.

The following conclusions were drawn: 1) Areas below water level are best protected by an impressed current; 2) Encasing the splash area in concrete or sheathing it with a resistant metal might afford protection; and 3) The area above the splash area is best protected by zinc coatings or paints.

4.6.11, 7.2, 6.3.6
Recent Experiences with Corrosion and Wastage of Copper Circulating Piping in Ships' Machinery Spaces. D. C. MACMILLAN AND G. G. SHARP. Soc. Naval Architects and Marine Engrs., Typescript, Jan. 26, 1950, 6 pp.

Gives details of practical experience of corrosion of ships' seawater circulating pipes. Bare copper often fails prematurely by impingement attack and tin- or lead-coated copper is also unsatisfactory. Trials are now being made on cupro-nickel and Monel pipe and rubber-lined pipe.—BNF.

4.6.12, 5.1
Requirements of Subsurface Injection Water in Oil Production. K. H. ANDRESEN AND F. T. GARDNER. *Oil Gas J.*, **49**, No. 18, 72-77 (1950) Sept. 7.

In the displacement of oil by water, the properties of the raw-water supply chosen should have little or no effect on injection rate and must not lead to plugging or mechanical failure of the injection system. The presence of corrosion products may be serious and means for reducing this occurrence are exclusion of air from the gathering and injection system, elevation of pH of water, use of corrosion-resistant materials, application of corrosion-resistant coatings and addition of corrosion inhibitors. Consideration has been given to corrosion-resistant alloys such as Monel, aluminum and nickel steels for construction systems particularly for subsurface equipment.—INCO.

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2, 7.2, 3.3

Use of Magnesium Anodes for the Protection of Pipe Lines. W. F. Higgins. *Magnesium Rev. and Abstracts*, **3**, 99-119 (1949) Dec.; *Civil Eng.*, **44**, 712-715 (1949) Ibid **45**, 43-47 (1950).

Deals with theory and process of corrosion, theory of protection, requirements of a galvanic anode, magnesium as an anode, bacterial corrosion of iron pipes, practical implications of the method, pipeline surveys, electrical connections to pipe lines and special anodes. Concerned for the most part with cast-iron and steel pipe.—BLR.

5.2, 4.6, 7.4

Cathodic Protection for Open-Box Type Coolers. C. R. Draughon, Jr. and E. B. McNeil, Esso Standard Oil Co. *Oil Gas J.*, **49**, No. 4, 76-79 + (1950) June 1; *Petro. Ref.*, **29**, No. 5, 97-103 (1950) May.

An attempt is being made to retard or prevent water-side corrosion in open-box coil coolers by use of cathodic protection. Corrosion on the water side of tubes was in the form of tubercules, which resulted in deep pitting and short life. Several methods of corrosion control were considered along with cathodic protection. Description of the installation includes the cooler, rectifier, anode and electrical systems. Numerous surveys made on the cooler box consisting of pipe-to-water potential and current density measurements are discussed. As a result of the surveys additional steps were taken by the addition of more anodes and by increasing the rectifier output. Description and figures are included for other coolers.—INCO.

5.2.2, 1.7.1

Condensation of First Interim Report on Galvanic Anode Tests of Sub Committee TP-2 — Galvanic Anodes for Cathodic Protection. NACE Tech. Report, Publ. 50-2. (Digest) *Corrosion*, **6**, No. 8, 274-275 (1950) Aug.

Tests are being made to determine what the effect of impurities in metals, suitable for galvanic anodes for cathodic protection in soils and solutions, may have on the solution potential, resistance of the corrosion products and current efficiency. Performance curves for zinc and magnesium anodes are presented and data include the current output, resistance to earth and solution potential of the anodes and the pipe-to-soil potential of the structure. Results show that zinc anodes backfilled with mixture of gypsum and clay have a relatively constant resistance to earth.—INCO.

5.2.1, 5.4.5

Progress Report: The Use of Cathodic Protection in Conjunction With Paint Coatings. W. L. CROSBY. *Corrosion*, **6**, No. 11, 383-388 (1950) Nov.; *Paint Var. Prod.*, **30**, No. 15, 9+ (1950).

Discusses problem of corrosion of steel tanks housing transformers and network protectors installed in manholes where they are subject to complete or partial salt-water immersion at high tide. Attempts to mitigate this corrosion

have led to two main investigations; selection of the best available paint system that can readily be applied; and determination of feasibility of applying cathodic protection in conjunction with this coating. Selection of the best paint system involved laboratory testing of approximately 100 different systems under conditions simulating those encountered in service. The study of cathodic protection in conjunction with a protective coating is still in its initial phases.—BLR.

5.2.2, 8.9.5

Use of Magnesium Alloy Anodes in Ship Protection. K. N. BARNARD. *Can J. Research,* Sec. F, **28,** 417-437 (1950) Nov.

The results of a 14-month test of magnesium alloy anodes in sea water are described. The anode current was used to protect cathodically an inactive minesweeper. The results obtained show that it is practical to use magnesium alloy anodes at two positions 16 ft. deep in ship protection and that only a relatively small current is required to prevent the corrosion of underwater hulls of inactive ships. An average value of about 1.5 ma per sq. ft. appears ample. This makes installation more economical and material cost is also less since this current requirement could be provided by the consumption of about 220 lbs. of magnesium per year. A convenient criterion to determine the amount of current required is given.

5.2.2, 4.6.11, 8.4.3

Coating from Sea Water. *Metal Industry* (England), **77,** No. 9, 130 (1950) Sept. 8.

Steel supporting platforms for oil drilling gear off-shore in the Gulf of Mexico are being protected against corrosion by a protective coating produced by cathodic protection with magnesium anodes. Two types of anodes are used: The "Galvo-Line" in the form of a ribbon and 51 lb. permanent anodes. The "Galvo-Line" produces a high current density for a short period of time during which a coating of calcium and magnesium in the form of carbonate and hydroxide is formed on the steel surface. This process, known as the Cox marine electroplating process, is carried out with current densities of 30 to 35 mA per sq. ft., with 100 to 200 mA per sq. ft. giving the most protective coatings. The anode is dissolved away in about 8 days but the coating reduces the current required for the protection of the steel and can be maintained by as little as 3 mA per sq. ft. supplied by the permanent anodes. Each of these anodes can supply protective current for 600 sq. ft. of surface for two years. The coating produced has the valuable property of continuing protection in the absence of maintenance current should the anode be torn away. —ALL.

5.2.4

Determination of Current Requirements for Cathodic Protection. M. E. PARKER. *World Oil,* **131,** No. 6, 253-256+ (1950) Nov.

Methods are described for application to pipe lines, tank bottoms, structures in sea water, water tank interiors, and miscellaneous minor applications. Undeveloped applications such as the interior surfaces of water pipes are also discussed briefly.

5.3 Metallic Coatings

5.3.2

Thin Electrodeposited Coatings. M. MASSARD. *Rev. gen. Mecan.,* **34,** No. 20, 330 (1950).

A note on the protection afforded by a number of thin electrodeposited coatings applied to iron, steel, aluminum, zinc and copper alloys, with particular reference to coating thickness.—MA.

5.3.2, 5.4.5

Corrosion Prevention With the Metco Metallizing Systems. Bulletin 93. Metallizing Engineering Co., Long Island City, N. Y.; 1950. 3 pp.

The Metco systems provide pure zinc or aluminum coatings treated with vinyl, vinyl-alkyds, chlorinated rubber or other coatings to withstand various corrosive conditions.

5.3.2, 5.3.4

Hot-Dipped Aluminum Coatings on Steel Sheet. *Mech. World Eng. Record,* **128,** 303 (1950) Sept. 29.

Aluminum coatings formed on steel by hot dipping vary from ½ to approximately 3 mils (1 mil = 0.001 inch) in thickness, possess good continuity and a relatively thin interfacial layer. An American company is now using this method to produce "aluminized" steel sheet on a commercial basis. The process involves pre-heating the steel in a controlled atmosphere before it enters the aluminum bath. Other aluminum hot dip processes are similar to hot dip galvanizing, using a pickle followed by a molten flux, after which the steel enters the molten aluminium bath. To permit bending and forming of coated products, the brittle interfacial layer must be kept at minimum thickness. This can be accomplished by the addition of silicon to the aluminum coating bath. Temperature is another important factor in the coating bath, as an increase in temperature tends to increase the thickness of the interfacial layer.—TIME.

5.3.2

Finishing Operations on Springs. *THA Supp. to Machinery,* **76,** No. 1968, 61-67, **1950,** Sept. 28.

A general account of the finishing of steel and non-ferrous springs, with observations on the service for which each finish is suitable. Cadmium plate is recommended as the most satisfactory all-round coating; at least 0.0003-in. should be applied. Zinc, plated, sprayed or applied by hot dipping, is said to be nearly as good, except that hot dipping reduces the life of a spring to a marked degree under fatigue conditions. Cadmium coated springs may be used at temperatures up to 600° F, but 400° is given as the upper limit for zinc. Plated or sprayed zinc coatings are said to be beneficial in counteracting corrosion fatigue. The avoidance and elimination of hydrogen embrittlement, which may arise in pickling or plating are also discussed.—ZDA.

5.3.2, 5.3.4

Coating of Steel With Aluminum. S. L. CASE. *Steel Proc.,* **36,** 435-439+ (1950) Sept.

One of a series of articles based on a book now in preparation: "The Alloys of Iron and Aluminum," by S. L. Case and Kent R. Van Horn (Alloys of Iron Monograph Series). Describes Calorizing (a diffusion-coating process); hot-dip

coatings; Aluminizing; and other methods. Also describes Al-Fin process for bonding aluminum or its alloys to steel or cast iron.—BLR.

5.3.4, 5.9.1, 5.4.5

The Fight Against Metallic Corrosion and Wear by Means of Surface Treatments. M. BALLAY. *Rev. gen. Mecan,* (N.S.), **34,** No. 19, 271-277 (1950).

A brief survey of methods of treating metal surfaces to prevent corrosion and wear. These include: a) application of a metallic coating by hot dipping, metal spraying, electrodeposition, and cladding; b) surface modification by cementation, chemical or electrolytic oxidation, phosphating, and miscellaneous chemical, mechanical, electrolytic, or thermal treatments; and c) non-metallic finishes such as paint, varnish, enamel, and plastics.—MA.

5.3.1, 5.4.1, 6.2.3

Finishing Steel for Decorative and Protective Purposes. REID L. KENYON, Am. Iron and Steel Inst., New York, Preprint (1947) 28 pp.

Reviews developments in nonmetallic finishes, electroplated and hot-dip metallic coatings, combined metallic and nonmetallic coatings, porcelain enamels, stainless steel and special finishes.

5.3.4, 6.4.2

Plating on Aluminum and Its Alloys. R. H. Keller. *Plating Notes* (Australia), **1,** No. 3, 66-93 (1949).

Various methods which have been used are reviewed, and their history traced. Special surface treatments are required before plating and these are discussed under the following headings: a) pre-plate anodizing, b) heavy-metal dips, and c) immersion deposition. Zinc-immersion pretreatment consists essentially of depositing a film of zinc on the clean aluminum surface from a bath containing sodium zincate, and this widely-used method is described in detail.—ALL.

5.3.4, 8.9.3

Field Application of Alloy Strip Liners Inside Refinery Vessels by Welding. *Petro. Proc.,* **5,** 1085-1086 (1950) Oct.

Principal lining materials used are Types 405 and 410 stainless steels, 5/64-in. thick, with electrodes of 25-20 chromium-nickel alloy. Good results are obtained with 2-bead welding on a vertical strip installation. Considerable attention is given to surface preparation.—BLR.

5.3.2

Cadmium Applied as an Intermediate Deposit in Bright Chrome Plating on Iron and Steel. B. M. Pearson. *Prod. Fin,* **3,** No. 7, 84-86 (1950) July.

A description of the plating process described in German Patent 458,632. The cadmium deposit, applied under the chromium, gives good protection against corrosion, is easily polished and is free from pores. Careful control of cadmium plating baths is necessary if good results are to be obtained and the bright chrome should be applied immediately after the cadmium has been deposited. Various proprietary cadmium cyanide baths are discussed and it is suggested that Turkey Red Oil is a useful brightening agent.—ZDA.

5.3.2, 5.4.5

Metal Organic Coating. *Chem. Eng,* **57,** No. 8, 145-146 (1950).

To provide long time protection on

tanks and other steel structures for periods ranging even up to 25-100 years, a group of corrosion prevention systems was developed consisting in the spray application of pure zinc or aluminum, which is then usually given a specific organic treatment depending on service requirements. The organic coating firmly keys to the zinc or aluminum and is said in itself to provide years of protection. When finally this coating weathers away the anodic protection of the zinc or aluminum is still available. If necessary, the organic coating may be reapplied at long intervals without descaling or other expensive preparation. Although various combinations of metal and organic coating are used, in general, the organic coating is a vinyl or a chlorinated rubber.—INCO.

5.3.2, 5.9.4

A Report On Some New Zinc Coatings. A. E. CHESTER. *J. Amer. Zinc Inst.,* 28, 61-7+ (1950).

A paper presented at the American Zinc Institute's meeting in April 1950. The author describes the results of six years work in one laboratory to study and improve zinc coatings. It has been found possible to deposit mirror-bright zinc from a zinc sulphate solution containing a metallo-organic brightener. The process is said to be much cheaper than cyanide bright zinc plating. The brilliance diminishes somewhat as the thickness of the zinc increases. Reference is also made to the valuable properties of bleached chromate films on plated zinc to prevent white rusting and to the experimental extension of this treatment to include hot dip galvanized.—ZDA.

5.4 Non-Metallic Coatings and Paints

5.4.5

Blistering of Paint Films. I—Blistering in the Absence of Corrosion. J. E. O. MAYNE. *J .Oil Col. Chem. Assoc.,* 33, No. 361, 312-316 (1950).

Polystyrene films, plasticized with chlorinated diphenyl (I), methyl styrene (II) or tricresyl phosphate (III), supported on clean glass plates and subjected to various ageing schedules, were immersed in distilled and sea-water, and the degree of blistering noted. Blistering was greater in distilled water, and varied with the plasticizer in the order II III I. The blisters contained no liquid. It is concluded that blistering of this type (in the absence of corrosion) is due to expansion of the film on sorption of water and its consequent detachment from the glass surface.—RPI.

5.4.2

Single Coat Porcelain Enamel Finish. M. E. McHARDY. *Refrig. Eng.,* 57, 244-246 (1949) Mar.

A manufacturer's experience with single coat porcelain enamel on steel refrigerator parts is reported. Titanium steel, due to its sag resisting properties, has helped solve the problem of warping of open flanges on large parts. Some redesign is necessary with the new steel. Production was started in 1946 using titanium steel and zirconium cover coat enamel. On interior parts one coat and one fire is used. Exterior parts are processed with two coats.—RA.

5.4.3, 8.8.5
Nordac's Rubber Lined Pickling Tanks. *Mining J.*, **234**, No. 5993, 684 (1950) June 30.

A description of the method of lining pickling tanks with acid-resisting rubber sheets, of from 1/32-in. to ¼-in. thick. The rubber sheets are fastened to the inside of the tank with a special cement, and adjacent ones are joined by "welding" with hot iron rollers. After final vulcanization, the rubber literally forms one with the basic structure.—ZDA.

5.4.5, 5.4.8
Protective Coatings in the Corps of Engineers. G. S. COOK. *Off. Digest*, **306**, 541-555 (1950) July.

A review of paint research in hand at the Fort Belvoir Engineer Research and Development laboratories. The work covers the protection of dam gates; interior and exterior paints for barracks; the relative merits of different chromate pigments in primers; fire retardant paints; and fungus control. Several formulations embodying zinc pigments are quoted as being under test, but no detailed results are given.—ZDA.

5.4.5, 7.2, 8.9.3
Anti-Corrosion Tape for Service Pipes. G. M. Carter, Jr. *Gas Age*, **106**, No. 11, 42-43+ (1950) Nov. 23.

Use of a polyvinyl chloride "Scotch" tape for protection of a gas company's service pipes against corrosion is described. Advantages and method of application are presented.

5.4.2, 6.4.2
Vitreous Enamelling Broadens Scope of Aluminum Applications. N. BRUCE BAGGER. *Mat. and Meth.*, **30**, No. 5, 55-56 (1949).

Details of a new enamelling process for aluminum and its alloys are given. The enamelled aluminum can be cut and slightly bent or formed without the enamel cracking and is very resistant to the action of mild acids.—MA.

5.4.8
Colour Engineering in Plant Maintenance. F. J. KULLENBERG. *Pacific Factory*, **73**, No. 3, 30+ (1950).

Color engineering is the correctly planned application of color in relation to the job to be done, the place in which it is done, the equipment to be used in doing it, and the people who are working on it. Color can be used to develop a sense of good housekeeping, minimize the effect of bulk or weight, visually eliminate undesirable structural features, minimize illumination costs, eliminate certain hazards, and change the apparent temperature of a working area.—RPI.

5.4.7
Steam-Spray Painting. *Ind. Fin.*, **26**, No. 7, 118 (1950).

Steam is used instead of air as the carrier in a spray painting process. A film thickness of 2 mils is obtained for one pass of the gun. Loss from overspray is less, and less thinner is used.—RPI.

5.4.5
Rust Protection of Iron Structures. K. KRENKLER. *Gas- u. Wasserfach*, **90**, 641-643 (1949); **91**, 60-63 (1950); *Werkstoffe u. Korrosion*, **1**, No. 5, 193; No. 6/7, 291 (1950).

For efficient protection, pigmented varnishes should be used. The pigments fall into 3 classes, viz., 1) those chemi-

cally inactive, e.g., iron oxides; 2) active pigments such as zinc oxide which react with the fatty acids of the medium; and 3) pigments having a physical action, e.g., aluminum power.—RPI.

5.4.7, 5.4.5
Coating With Polythene. *Brit. Plastics*, **23**, 56-59 (1950) Aug.

Describes and illustrates equipment and procedures for application to metals and nonmetals.—BLR.

5.4.5
Rust-Inhibitive Lead Pigments. Monsanto Chemical Co. *Paint Varnish Production Mgr.*, **30**, No. 7, 25 (1950).

Tri-lead orthophosphate and di-lead pyrophosphate are rust-inhibitive pigments non-reactive to polyvinyl chloride-acetate copolymer solutions and to acidic media.—RPI.

5.4.5, 5.8.4, 5.9.4
Chromate Protection for Metals. Anon. *Chem. Age*, **63**, No. 1621, 199-200 (1950).

The various aspects of the use of chromates in the prevention of corrosion are discussed, including the use of chromate pigments in anti-corrosive paint primers, the chromatizing of metals and the use of soluble chromates as corrosion inhibitors.—RPI.

5.4
Anti-Rust Paints Using Glycerophthalic Resins. M. Lambert. *Trav. peinture*, **4**, No. II (Special No.), 34 (1949).

Anti-rust pigments may act either: a) in primers, by virtue of their chemical nature, or b) in finishes, by their structure (usually lamellar). Older types of anti-rust paints were based on linseed or tung oil, but the use of alkyd resins gives paints of improved durability.—RPI.

5.4
Plastics. G. M. Kline. *Ind. Eng. Chem.*, **41**, No. 10, 2132-2137 (1949); cf. *Review*, 1376 (1949).

Considerable development has been noted in polyethylene and polymers of ethylene containing flourine and chlorine, polytetrafluoroethylene being extremely resistant to chemicals. Vinylbased primers containing phosphoric acid and zinc chrome have been used successfully on steel, aluminum, copper, etc. Furfuryl alcohol resin coatings have been used for corrosion-resistant finishes.—RPI.

5.4, 1.3
Physical Chemical Research in the Protective Coatings in Industry. R. H. Kienle. *Off. Dig.*, No. 300, 11-52 (1950).

A comprehensive review covering recent research in the field of paints, solvents, media and pigments, with 25 refs. —RPI.

5.4, 8.9
Fire-Resistant Finishes for Aircraft. J. A. Jones and R. V. Niswander. *ASTM Bull.*, 59-60 (1950) May.

Describes development of a testing apparatus by which a realistic comparison can be made of combustible materials under conditions simulating those of an actual fire. A refractory coating material has been developed which is considered to provide satisfactory protection for certain critical aircraft components. Paint-type coatings have been produced which puff when subjected to heat and fire, and form an insulating foam. However, the protection afforded by these

coatings is only marginal for aircraft applications. Test results indicate greater need for improvement in film characteristics than for improvement in fire protection.—BLR.

5.4, 2.3
Anti-Corrosive Power of Paints Determined by Measurement of Electrode Potentials. E. Jimeno, S. Medina-Castellanos and J. Aravio-Torre. *Inst. Espan. Oceanog., Wire & Wire Prod.*, **25**, No. 4, 336-337 (1950) Apr.

The electrode potential of cells: Iron/normal sea water and painted iron/normal seat water were measured against the normal calomel electrode. A comparison was made of the electrode potentials of iron covered with various paints with linseed oil. The change in potential produced when painted iron in contact with sea water was scratched was measured. A comparison of the data under the three conditions permits classifications of each of the paints from the point of view of mechanical protection and active protection. A microscopic examination of the steel specimens was made and this data compared with the electrochemical results.—INCO.

5.4, 4.6
Researches on Under-Water Paints for Structural Steelwork. W. Husse. *Farbe u. Lack*, **55**, No. 12, 441-444 (1949).

A variety of paint systems, based on drying oils, bitumen, chlorinated rubber and benzyl cellulose, were examined for resistance to fresh and sea water when painted on steel panels. Hot-applied coal-tar pitch pigmented with microasbestos proved best in fresh water. In sea water, no system was decidedly superior, but chlorinated rubber paint suffered little damage on being exposed; no marked difference was observed between pitch and red-lead/oil paints.— RPI.

5.4, 2.1
Protective Coatings and Their Use in the Building Industry. H. Rabate. *Cashiers Centre Sci. Techn. Batim.*, No. 53, 1-41 (1949); *Peint pig vernis*, **25**, No. 12, 454 (1949).—RPI.

5.4
Chlorinated Rubber in the Paint Industry. B. S. Giovani. *Paint Manuf.*, **29**, 419-424 (1949) Dec.

Use of chlorinated rubber paints for noninflammability and resistance to water, water vapor and various corrosive vapors and liquids. Use for protection of iron and steel structures against fumes. 21 ref.—MR.

5.4, 6.4, 2.3
New Seal Primer for Aircraft Finishing. Gilbert C. Close. *Prod. Fin.*, 14, No. 6, 44-45 + (1950).

The use of an alkyd resin/zinc chromate primer for protecting aluminum and magnesium is described. It is claimed to be an improvement on conventional zinc chromate primers not containing alkyd resin. Brief details are presented of tests carried out on aluminum and magnesium using various protective coatings. All test panels were submitted to exposure for 2300 hr in a salt spray. All the aluminum panels treated with the conventional primer showed some measure of breakdown of the paint, whereas those coated with the modified material were perfect. The magnesium panels had received a coat of enamel in addition to

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the primers. Those on which the conventional primer had been used were badly corroded and those with the modified primer very much less so. The modified material is shown to be superior to the other by a number of other tests. —MA.

5.4

Aluminum Stearate in Protective Coatings. Paul N. Cheremisinoff. *Am. Paint J.*, 34, 90-92 (1950) Aug. 7.

Discusses properties and advantages of the above.—BLR.

5.4

Corrosion. R. Clark. *Can. Metals Met. Inds.*, 13, No. 5, 38, 40 (1950) July.

Advances made in efficiency and effectiveness of processed fish oil (with pigment) are most outstanding. Treated to remove the odor and pre-oxidized to hasten drying, the fish oil base coating still retains its rust inhibiting characteristics.—INCO.

5.4, 8.8, 4.3, 4.4

Corrosion-Resistant Plastic Coatings. *Chem. Eng.*, 57, No. 5, 198 (1950) May.

The first group of new plastic-base coatings, known as the V-200 series, is recommended for use over metal, wood, or concrete wherever a simplified coating system is required to withstand the corrosive vapors present in chemical or processing plants. The V-200 coatings may be applied by spray, brush, or dipping. They can be air-dried quickly or baked to yield a flexible, abrasion-resistant coating highly adherent even to polished metal surfaces. Corrosion-inhibitive pigments within the system protect

metals from under film corrosion. This gives the coating long life even when exposed to salt atmospheres, alcohols, soaps, fruit juices, acids, alkalies, petroleum products or related corrosives. Mfd. by Specialty Coatings Lab.—INCO.

5.4

Correlation of Weather Resistance of Porcelain Enamels with Chemical-Test Data. B. J. Sweo. *J. Am. Ceram. Soc.*, 32, No. 11, 356-359 (1949) Nov.—MI.

5.4, 4.1

Corrosion-Resistant Finish. *Elec. Mfg.*, 45, No. 4, 146-148 (1950) Apr.

For effective protection of surfaces exposed to atmospheric and corrosive conditions, a rust-inhibitive protective coating, "Kem-ban," has a copolymer resin as a binder and incorporates rubber derivatives as plasticizers. Formulation is effective against rust and resistant to acids, alkalies, chemical fumes, moisture, salts and alcohol. The coating is a fire-retardant film of uniform thickness, has a high hardness and sufficient elasticity to allow for expansion due to temperature changes. It is available in several colors. Mfg. by Ace Laboratories.—INCO.

5.4, 6.4

"The Surface Hasn't Been Scratched." *Martin Star*, 1950, July, 12-13.

A new scratch- and wear-resistant hard coating for aluminum has been developed which, for the first time, makes this light metal eligible for many applications largely monopolized by steel alloys. Designated as "MHC" finish, the new Martin hard coating has been ap-

plied with outstanding success to such widely dissimilar aluminum items as gears, pinions, surveying instrument parts, turbine impeller blades, hard tools, swivel joints, leading edges of high-speed airfoils, cams and leg braces for paraplegics. Many direct MHC-finished aluminum substitutions for steel are being made in the case of moving parts for Martin airplanes, as well as static surfaces exposed to severe scuffling or other forms of wear. The finish is applied by an electrochemical process which creates a nonmetallic, file-hard, highly heat-refractive surface, strongly bonded to the base metal. The film is a nonconductor and is protective against most commonplace chemicals, though it is attacked by strong acids or alkalies.—TDD.

5.4, 3.5

New Non-Inflammable, Anti-Corrosive Paint from Australia. C. Lynch. *Peint. Pig. Vernis*, 25, No. 12, 449 (1949); cf. Review 178 (1948).

Butyl titanate as a medium for paints withstands temperatures in excess of 540 degrees C. In addition, these paints possess good anti-corrosive properties.—RPI.
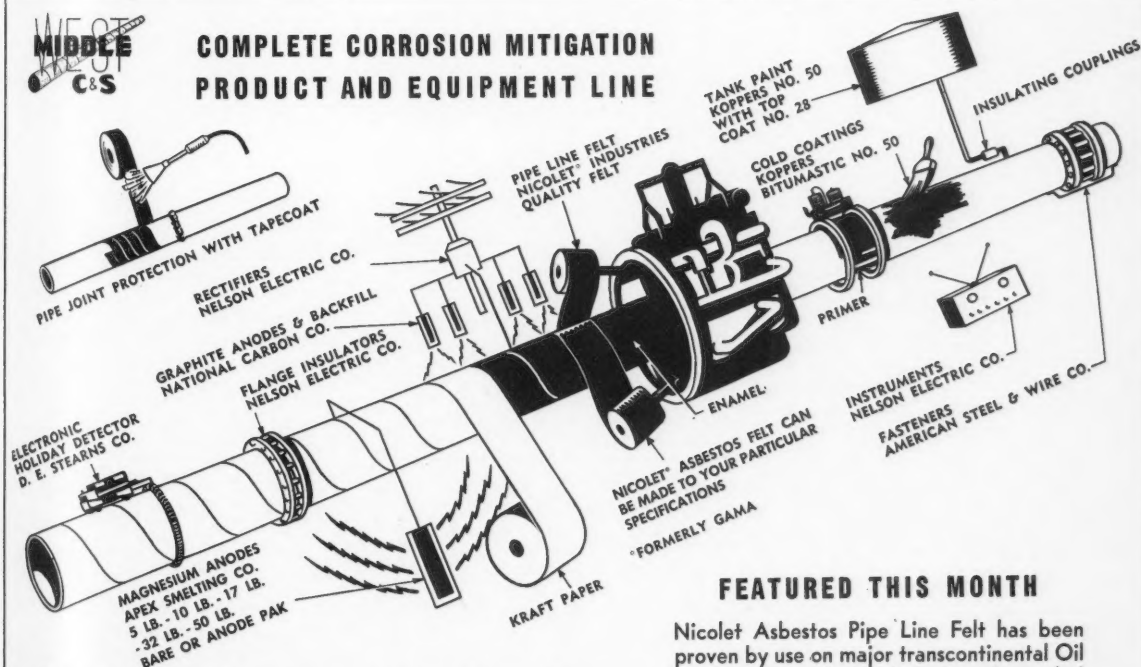
5.4, 2.4

Adhesion and Application of Organic Coatings to Metal. B. M. Letsky. *Paint Manuf.*, 19, 425-426, + (1949) Dec.

Investigation of the thermodynamic changes which occur during the wetting of metallic powders and oxides by organic liquids and media. "Adherometer" developed to measure force of adhesion of organic coatings.—MR.

5.4, 6.3, 3.4

Soil-Corrosion Studies, 1946-1948: Copper Alloys, Lead and Zinc—RP No. 2077. I. A. Denison and M. Romanoff. *J. Research Nat. Bur. Standards*, **44**, No. 3, 259-289 (1950) Mar.

Contains the results of measurements of corrosion made on specimens of copper, lead, and zinc and of alloys of these metals exposed to different soil conditions for periods up to 14 years. The loss in weight of the copper zinc and 74.45 copper-20.04 nickel-4.99 zinc alloys was approximately in the order of increasing zinc content except in soils high in sulfides in which the reverse order was followed. In general, copper, zinc and lead and alloys of these metals were corroded most severely in poorly aerated soils, particularly, in soils that were highly acid or that contained high concentrations of soluble salts. Copper was corroded in soils high in sulfides. Lead was passivated by soils containing high concentrations of sulfates and chlorides. Many charts, photographs and diagrams. 10 references.—INCO.

5.4

Electricity and Paint Films. N. R. Fisk. *Paint Tech.*, **14**, No. 168, 331-332 (1949).

The presence or absence of polar groups in paint films determines their degree of adhesion to surfaces. The anticorrosive properties of a paint film are dependent on its ability, 1. to prevent ions from the substrate from passing into solution, 2. to reverse the flow of current, making the metal substrate cathodic and the protecting film anodic (e.g., zinc dust paints), 3. to stifle one or other of the electrodes. The ideal coating is one which hinders the passage of water to the substrate. Thick multi-coat systems retard corrosion by virtue of their barrier action. The presence of pores in a film will concentrate the current at the weak points in the film and cause pitting there.—RPI.

5.4, 5.9

Protective Coatings for Metals. U. R. Evans. U. N. Sci. Conf. on Conservation of Resources. *Times Rev. Ind.*, **4**, No. 37, 22-24 (1950).

The writer suggests protecting steel with organic coatings such as styrene and vinyl compounds and tar products to overcome the shortage of drying oils. It is essential that cold-rolled steel must be freed from grease, rust and all mill scale before painting. A phosphate layer will prevent under-rusting and provide a key for the paint. Where all the rust and mill scale cannot be removed before painting, red lead will give more efficient protection than any other anticorrosive primer. Other methods for steel protection are given. The theory underlying corrosion is outlined and explanations are given for many paint failures.—RPI.

5.4

Paint Principles. U. R. Evans. *Chem. Eng.*, **57**, No. 2, 240 (1950).

The protection of steel is best achieved by the inclusion of an inhibitive pigment in the priming coat. The outer coat should prevent the mechanical and chemical breakdown of the primer. The protection given by a red lead/linseed oil system is attributed to soap formation.—RPI.

5.5 Oil and Grease Coatings

5.5.3, 2.2.2, 2.3.2

Temporary Corrosion Preventives for Aviation Uses and Methods of Testing Them. E. W. J. MARDLES AND J. MASON. *J. Inst. Petro.*, **36**, 475-487 (1950).

Numerous temporary corrosion preventives are mentioned, including corrosion-preventive lubricants, all of which have been used in connection with aviation. Special features of these temporary protectives are briefly discussed. Methods of testing are considered: Exposure, Accelerated, Mechanical, Special Tests for Engine Corrosion Inhibitors, Bomb Oxidation Tests, and Other Laboratory Tests. Typical results of the Norma-Hoffmann Bomb Oxidation Tests are given and discussed. The importance of this method of testing and the development of temporary protectives and similar products, is stressed.—PR.

5.5.3, 1.3, 2.3.2

American Methods of Testing Temporary Corrosion Preventives. C. F. McCUE AND E. R. BLANE. *J. Inst. Petro.*, **36**, 487-494+ (1950) Aug.

A critical review.

5.6 Packaging

5.6.1

Corrosion Protection of Stored Plant and Machinery. McAulay. *Iron & Coal Tr. Rev.*, **161**, No. 4298, 187-190 (1950).

5.6.3, 6.2.3

Protection of Steel in Transit. A. H. ANDREWS. *Am. Iron & Steel Inst.* Yearbook, 1950, 469-486.—BNF.

5.6.2

Plastic Spray Packaging. *Paint Manuf.*, **20**, No. 7, 251-254 (1950).

The application of cocoon coatings for corrosion protection is described. The coating consists of a mixture of a plasticized vinyl chloride/acetate copolymer and vinylidene chloride/acrylonitrile copolymer.—RPI.

5.6.1

Packaging — Get Set Now for Fast Changes. *Modern Ind.*, **20**, No. 6, 38-44 (1950) Dec. 15.

The problems concerned with the packaging of materials are discussed in the light of new military packaging demands and spot material shortages. The present trend is the standardization of packagings for reasons of economy and appearance; fractional, or small unit packaging; and use of new materials, such as "Drumpak," solid-fiber, or wood-reinforced cleated fiberboard boxes, etc. An assessment is made of the current availability of various packaging materials and tips are given as to where packaging specifications may be obtained for government materials.—TDD.

5.6.1, 2.3.2

The Nature and Scope of Temporary Corrosion Preventives. D. CLAYTON AND M. C. THOMPSON. *J. Inst. Petro.*, **36**, 423-428 (1950).

The broad purpose of temporary cor-

rosion preventives is to protect metal surfaces against corrosion during transport and storage, and in such manner that articles can be restored to their original state by easy removal of the protective film, mainly through the use of common petroleum solvents. Most such preventives function by providing a water-resistant barrier and by forming an absorbed layer on the metal. The usual types of temporary corrosion preventives are given, together with some of the newer developments. The field of use is defined, and the principal causes of failure reviewed. Finally, some of the questions arising in accelerated testing are raised.—PR.

5.7 Treatment of Medium

5.7.4, 7.5.5

Reduction of Tanker Corrosion. *Comp. Air Mag.*, **55**, 107 (1950) Apr.

Corrosion in tankers can be reduced as much as 80 percent by lowering the humidity inside the tanks. A machine called the Cargocaire maintains a supply of desiccated air above the liquid in the tanks during transit and also keeps the piping system filled with dry air. Emptied tanks are charged with dry air, which not only protects them from corrosion but forces out residue gases that might cause explosion.

5.7.7, 8.4.3

Neutralization as a Means of Controlling Corrosion of Refinery Equipment. E. O. CAMP AND CECIL PHILLIPS. *Corrosion*, **6**, No. 2, 39-44+ (1950).

A summary of the results obtained by using neutralizers as a means of controlling corrosion of refinery equipment. The methods employed in injecting sodium hydroxide, ammonia, and lime are described and results obtained on the use of ammonia in controlling corrosion of equipment in connection with distillation, cracking, gas absorption, debutanization and steam systems are given in detail.—MA.

5.8 Inhibitors and Passivators

5.8.2, 5.6.3, 4.6.4

Sodium Benzoate as Inhibitor. *Chem. Trade J.*, **124**, 242 (1949) Mar. 4.

Sodium benzoate has been found effective as a corrosion inhibitor in automobile cooling systems when added in small proportions to solutions of glycerine or glycol. The discovery has been applied to wrapping materials impregnated with sodium benzoate. Steel specimens in these wraps remain bright in conditions of high humidity, even if the wrapping becomes soaked with precipitated moisture. Sodium benzoate is a safe inhibitor in that if the concentration falls below the inhibiting percentage it does not induce corrosion and localized pitting.

5.8.2, 4.3.2

Amine Inhibitor for Acids. *Chem. Proc.*, **13**, No. 11, 23 (1950) Nov.

Corrosion of steel by 10 percent sulfuric acid can be reduced 60 percent by adding 0.25 percent of an Alrol Amine,

produced by the Alrose Chemical Co. The Alro Amines C, O, and S are high molecular weight tertiary amines.

5.8.2

Positive Prevention of Corrosion By A. C. Compounds. Lubricants Division, Manchester Oil Refinery Ltd., Manchester, 1950, 12 pp.

Suggested uses, and methods of application and removal are given for various AC anti-corrosive compounds.

5.8.3

The Mechanism of Inhibition of the Corrosion of Iron by Sodium Hydroxide Solution. J. E. O. Mayne, J. W. Menter and M. J. Pryor. *J. Chem. Soc.*, 3229-3236 (1950) Nov.

When iron, freed from its original air-formed oxide film, is immersed in dilute sodium hydroxide solution containing dissolved oxygen, it becomes covered with a thin film of ferric oxide which is believed to be responsible for passivity. A de-aerated solution of sodium hydroxide attacks iron very slowly.

5.8.2, 4.6.6

Calgon Controls Corrosion. Calgon Inc,. Pittsburgh, 1949, 6 pp.

Calgon when added to water forms a protective film of a complex calcium phosphate containing some iron over the metal surfaces in a water system. The film does not build upon itself and concentrations of 1 or 2 ppm in cold water and 5-10 ppm at elevated temperatures are sufficient. Calgon is effective at all pH values above 5.0.

5.8.3, 7.5.5

Tank Linings for Electroplating. G. T. Colegate. *Intern. Chem. Eng. Process Ind.*, **31**, No. 449-451 (1950) Oct.

Article describes the characteristics and discusses the limitations of tank lining materials used in the plating industry. Materials dealt with are lead, asphalt, natural and synthetic rubber, polyvinyl, chloride, polythene and methyl methacrylate. Stainless steel is also used widely as a lining material for mild steel tanks, which are the easiest to coat. In nickel plating operation, choice of wood to protect primary lining is important since some, containing an excessive amount of resin, may seriously contaminate the solution. There is no single tank lining suitable for use under all conditions of electroplating, but the range of available materials is so wide that a satisfactory one can be found for most conditions, even exceptional ones.—INCO.

5.9 Surface Treatment

5.9.4, 6.4.2

Corrosion-Resistant Finish for Aluminum Alloys. *Metal Finishing*, **48**, No. 10, 84 (1950) Oct.

A chemical coating process for the surface protection of aluminum alloys, known as the Pylumin process, has been announced by the Pyrene Manufacturing Co., Newark, N. J. The process consists of a single immersion in a bath which is maintained by means of a simple test kit with the addition of a single chemical. The process is claimed to

clean the surface parts as well as providing a protective coating.—ALL.

5.9.1

Surface Preparation for Anticorrosive Coatings. C. G. Munger. *World Oil*, **131**, 174-177 (1950) Oct.

Demonstrates effects of various surface impurities and evaluates common methods for preparing surfaces for corrosion protection. Refers only to ferrous materials.—BLR.

5.9.1, 1.7.1

Recommended Practices for Surface Preparation of Steel TP-6G—Surface Preparation for Organic Coatings. NACE Tech. Report Publ. 50.5. *Corrosion*, **6**, No. 8, 276-282 (1950) Aug.

The paper discusses surface preparation for steel including surface oxidation by weathering, wire brushing, flame conditioning, blast cleaning, steel grit and shot blasting, chemical and electrolytic pickling. Surface cleaning with organic solvents, alkaline compounds and emulsions, surface reaction by acid cleaning and surface conversion are also discussed. Surface preparation of galvanized surfaces and maintenance and repair jobs are outlined.—INCO.

5.9.2

A Survey of the Chemical Aspects of Some Degreasing Processes Used for Metal Finishing. J. G. Baker. *Sheet Metal Inds.*, **27**, 737-742, (1950) Aug.

Describes trichlorethylene and wet degreasing and discusses their advantages and disadvantages. Considers need for two-step process.—BLR.

5.9.3

Belt Polishing and Dip Finishing of (Brass) Door Chimes. William R. Cutter. *Products Finishing*, **14**, No. 10, 28-32+ (1950).

Methods used for polishing seamless brass tubing are described.—MA.

5.9, 4.3

Protective Coatings. K. Tator. *Chem. Eng.*, **57**, No. 2, 216-218 (1950).

In many of the processes in which sodium hydroxide is used, it is a requirement that the material must be free from iron contamination. It is therefore necessary to protect the storage and processing equipment with a coating material which is resistant to sodium hydroxide. The choice of materials is a wide one and includes natural and synthetic rubbers, vinyl resins, poly-methacrylates, polystyrene, polyethylene and the nylons. Thickness of coating should range from 1/64 to 1/8 of an inch.—RPI.

5.9.2

Electric Burn-Off Oven Cleans Metal Stampings. J. I. Kolb. *Ind. Fin.*, **26**, No. 7, 71-72+ (1950).

Rust proofing compound and oil used in the forming process, are removed from stamped steel parts in an electric radiant heat oven operating at 400° F. The small amount of carbon left as a film on the surface has been found not to interfere with the adhesion of the aluminum paint subsequently applied.—RPI.

5.9.2

Alkaline Metal Cleaning Compound Specifications. A. Mankowich. *Plating*, **37**, No. 8, 843-844 (1950).

A laboratory-performance type of specification, as distinct from a composition specification is advocated. The main advantages claimed are that manufacturers are encouraged to develop improved and more economical products, because no restrictions are placed on the use of suitable raw materials, and in cases of emergencies leading to shortages, changes in formulation are quickly made, provided performance requirements are met. Points needing consideration in drawing up a laboratory-performance specification are outlined.—MA.

5.9.2, 5.9.3, 6.2.3

Removing Mill Scale From Steel. R. Mansell. *Org. Finishing*, **10**, 20-21, (1949); *Paint Notes*, **5**, No. 4, 117, (1950).

Several methods in use for removal of heavy scale and oxides from steel are described. Acid pickling processes are described. Inhibitors are essential in acid pickling baths in order to prevent attack on the underlying metal; thiourea is cited as a typical example. Temperature control is an important factor; installation of heating and cooling coils equipped with a thermostatic control is advised. The steel should be primed immediately after the pickling and washing process. Mechanical means of cleaning, such as with scrapers, wire-brushes, sand-blasting and flame cleaning, are discussed. Cleaning by scrapers and wire brushes is satisfactory for cast iron because of its freedom from mill-scale. Newly manufactured steel surfaces are best pretreated by sand-blasting. Where rust, mill-scale, etc., is to be removed on a large scale, flame-cleaning is recommended.—RPI.

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.5, 3.5.9

Stainless Can be Brazed for 2000° F Service. Part II. R. L. Peaslee and W. M. Boam. Wright Aero. Corp. *Iron Age*, **166**, No. 14, 84-87 (1950) Oct. 5.

The second and final installment of an article treating the brazing of stainless steel for service at temperatures up to 2000° F is presented. Exhaustive tests showed that points brazed in dry hydrogen, with a special brazing alloy and S-590 as base metal, have suitable physical properties for 2000° F service. It was found that tensile strength, yield strength, and proportional limit are generally as high as the base metal physicals at high temperatures. Oxidation resistance is excellent.—TDD.

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.6, 1.3

Wrought Copper and Copper-Base Alloys. C. L. Bulow. Bridgeport Brass Co., Bridgeport, Conn. *Ind. and Eng. Chem.* **42**, 1970-1977 (1950) Oct.

This review of 158 articles published during 1949 contains much information on the corrosion resistance and the physical, mechanical and fabrication properties of copper and copper-base alloys.

The corrosion articles deal with mechanisms, types, methods of inhibition and rates of corrosion in various environments. Soil exposures, marine exposures and corrosion in various industrial installations are discussed. The industrial environments include those of steam plants, petroleum refineries, pulp and paper plants, industrial gas and natural gas plants, as well as exposure to soap and fatty acids, motor fuels, insecticides, and aqueous salt solutions. —PDA.

6.3.6

The Ternary System Copper-Germanium-Silver. (In German.) H. Nowothny and K. Bachmayer. *Monatsh.*, **81**, 669-678 (1950) Aug. 15.

X-ray and metallographic studies and thermal analyses, are supplemented by corrosion tests. Includes constitution diagrams, photomicrographs and tables.—BLR.

6.3.14

Tin and Its Alloys. Robert J. Nekervis. *Ind. and Eng. Chem.*, **42**, 2020-2022 (1950) Oct.

Reviews fundamental and applied developments of the past year.—BLR.

6.3.1, 1.5

How to Select and Use Non-Ferrous Metals and Alloys. I.—II. J. W. Meier. *Can. Metals, Met. Inds.*, **12**, No. 8, 8-11+; No. 9, 12-15 (1949).

I. The availability, price, properties, and processing methods of non-ferrous metals and alloys are fully discussed and considerable tabulated data are given. II. The most important alloys of the

basic non-ferrous metals are briefly discussed in relation to their various industrial uses.—MA.

6.3.6, 3.6.5

The Behaviour of the Copper Electrode in Dilute Copper Sulphate Solutions. A. A. Mousa. *J. Chem. Soc.*, 1950, 403-404, Jan. Discussion of the paper by Tourky and El Wakkad, *ibid*, 749 (1948).

On the behavior of the copper electrode in dilute copper sulfate solutions. An alternative interpretation is put forward to explain breaks in the potential activity curves, which are assumed to signify a pure copper/cupric ion electrode reaction in solutions of cupric-ion activity, $a_{Cu}..$, lower than $\sim 10^{-4}$.—MA

6.4 Non-Ferrous Metals and Alloys—Light

6.4, 4.4

Aluminum Explosion Hazards — Violent Reactions with Chlorinated Hydrocarbons. *Chem. Age* (England) **63**, No. 1620, 155-157 (1950) July 29.

The Underwriters' Laboratories, Inc., Chicago, has investigated the reports that fires or explosions were caused by the reactions of aluminum with carbon tetrachloride or methyl chloride. Tests were conducted under various conditions using magnesium powder or aluminum exposed in contact with carbon tetrachloride, methyl chloride, trichloroethylene, dichlorofluoromethane, or carbon tetrachloride-chloroform mixtures. Results indicate that aluminum powder in contact with methyl chloride, carbon tetrachloride, or a carbon tetrachloride-chloroform mixture is capable of explosion; methyl chloride in contact with aluminum may form spontaneously combustible aluminum methyl. A bomb containing aluminum powder and carbon tetrachloride exploded violently after heating to 152 degrees C (305.6 degrees F) in 53 minutes. At ordinary temperatures (29.4 degrees C or 85 degrees F) and in the presence of a small amount of aluminum chloride as a catalyst, aluminum powder and methyl chloride reacted, first with the gradual formation of gaseous pressure in a closed bomb and after 41 days with more rapid pressure rise to more than 1800 psi. The residue of the reaction readily ignited spontaneously on contact with air or water and burned especially vigorously on water. Aluminum or magnesium with carbon tetrachloride, chloroform, or trichlorethylene did not explode readily when under impact tests of hammer blows. Fifteen tests were carried out at ordinary or moderately elevated temperatures and results are described and tabulated.—ALL.

6.4

Durability of Aluminum and Its Alloys. *Light Metals*, **13**, 195-203; 344-349 (1950) Apr., June.

Discusses corrosion resistance and applications of aluminum as contrasted with those of the heavy metals. Part Two reviews the corrosion resistance of the various composition groups.—BLR.

6.4, 4.2

Weathering of Some Aluminum Alloys. *Light Metals*, **13**, 215-221 (1950) Apr.

Describes experimental and service be-

havior of 2S, 3S, 50S, and 51S alloys after long exposure to rural, industrial, and maritime atmospheres. Illustrated. —BLR.

6.4, 3.5

On the Solubility of Chromium, Vanadium, Titanium, Manganese and Zirconium in Aluminum Alloys (Aluminum-Zinc-Magnesium and Aluminum-Copper-Magnesium. G. Siebel. *Z. Metallkunde* (Germany) **40**, No. **6**, 214-217 (1949).

A study was made of the solubilities of chromium, vanadium, titanium, manganese and zirconium, alone and in the presence of one another, in molten Hy43 (aluminum with zinc 4.5, magnesium 3.5, and manganese 0.2 percent) and of titanium and zirconium in molten Cu_2O (aluminum with copper 3.3, magnesium 1.6, and manganese 0.6 percent, at temperatures between ~ 650 and 850 degrees C (1202 and 1562 degrees F). At its mp ~ 638 degrees C (1181 degrees F), Hy43 dissolves 0.04, 0.21 and 0.09 percent of vanadium, chromium and titanium, respectively, but when all three elements are present together the solubilities decrease and become 0.03, 0.16, and 0.07 percent respectively; up to 0.44 percent manganese is soluble and may be present in the basic alloy without affecting the solubilities of these metals. The corresponding solubility of zirconium is 0.08 percent Cu_2O dissolves at its mp (~ 640 degrees C — 1184 degrees F) 0.20 and 0.16 percent of titanium and zirconium, respectively. Photomicrographs show and details are given of the following aluminides which were found and identified in the cast alloys: Al_7Cr, $Al_2Mg_3Zn_3$, Al_7V, Al_3Ti, Al_3Zr and Al_2Cu; Al_6Mn was not observed, owing to the low concentration of manganese present. It is concluded that for the production of good, large, continuously cast ingots of Hy43, close control must be maintained of the chromium, titanium, and particularly the vanadium contents of the melts, in order that the resulting ingots may be free from segregation and have excellent resistance to stress-corrosion.—ALL.

6.4

Modest But Varied British Light Metal Trials. *Oil Forum,* **4**, No. 3, 109-110 (1950) Mar.

Although British engineering circles believe economic utilization of aluminum is centered primarily in the transportation business, applications in the petroleum industry other than for tank-ship superstructures are believed to have great promise in regard to corrosion elimination. The steady reduction in cost of primary aluminum production as compared to high steel prices may cause potential expanded use of aluminum. Aluminum alloy piping has been tested for oil transmission lines and various ancillary equipment in refineries. Aluminum tanks and other containers have been developed, and extensive use has been made of aluminum alloy electrical conduit in oilfield and refinery installations and for andoic protection of pipelines. Alloys selected for these applications are mainly of the magnesium-silicide types, which have adequate corrosion resistance, high strength and good weldability. Experimental applications of aluminum in Britain have involved the production of extruded pipe and construction in the field has been either by argon-shield arc welding, bolting of flanges, or use of couplings. One instal-

lation is of bolted construction, the tubing having been expanded into flanges for the purpose. It was originally installed as a crude oil discharge line at the Purfleet jetty of Anglo-American Oil Co. Ltd. and has been used for the last 14 months as a product loading line to solve a particular corrosion problem encountered in handling solvent naphtha. Pressures exceeding 200 psi have been carried, and tests indicate maintenance is a negligible factor. The Royal Dutch-Shell has ordered 1000 feet of 4-inch OD aluminum-magnesium tubing in standard 30 foot lengths for its Venezuelan operations. The pipe is to be laid as a crude oil one under the waters of Lake Maracaibo to test its corrosion resistance compared with standard line pipe. W. P. Butterfield Ltd. is using aluminum for tanks to increase the effective payload of road transports hauling refined products. Aluminum has also been used effectively for chemical storage tanks.—ALL.

6.4

Durability of Aluminum and Its Alloys —Atmospheric Exposure. *Light Metals* (England) **13**, No. 151, 429-434, + (1950) Aug.

Service records of the corrosion resistance of aluminum cables, reflectors, building and architectural applications and paint when exposed to atmospheres and in some cases to soils are discussed. Electric cable of pure aluminum, aluminum alloys, or with a steel core have shown virtually no corrosion after service in rural, industrial and marine atmospheres in France, England, Germany, Switzerland and U.S.A. and under tropical conditions. Super-purity, commercial purity, or commercial purity sheet clad with super-purity aluminum is brightened, anodized and sealed for use in reflectors. The thickness of the anodic coating will vary with the severity of the exposure conditions. Frequent cleaning helps to minimize the corrosion of aluminum reflectors. Except in the most severe corrosive conditions such as exposure to chemical fumes, aluminum sheets need no protection and give good service in rural, industrial, marine and tropical atmospheres. Aluminum paint offers protection superior to other paints under all types of atmospheric exposure and under many conditions a coat of aluminum paint will last 10 or 15 years without repainting. The ability for aluminum paint to maintain its original luster is outstanding and it is unique in its resistance to sulfur and sulfur compounds. Results of tests to determine the comparative effect of hydrogen sulfide in discoloring aluminum and several white paints, showed that, although the aluminum paint lost some of its reflectivity, it did not yellow as did the other paints which had lower reflectivity in the beginning. Aluminum pigment is also used in heat resisting paints due to its resistance to corrosion by oxygen at comparatively high temperatures. The amount of attack on aluminum in foils depends upon the soil composition and climatic conditions, the attack being negligible in dry, sand soils, but more severe in wet, acid or alkaline ones. Tests have shown that aluminum alloys containing copper have the poorest resistance of the alloys. In well-drained soil, aluminum alloys showed superior corrosion resistance to steel and a lower percentage loss of tensile strength. Even in the cases where aluminum was corroded in marshy soil, such an attack would not be serious if thick-walled pipe were used.—ALL.

6.4, 3.4, 3.7, 5.9

Methods for the Protection of Magnesium Alloys. W. F. Higgins, Mg. Electron Ltd. *Electroplating*, **3**, No. 8, 287-29 (1950) Apr.

Corrosion protection of magnesium and its alloys is discussed. The strong mineral acids in aqueous solution attack magnesium rapidly, while the long-chain fatty acids are inert. The continuance of attack is dependent on the solubility of the product. Chromic acid brings on a passive condition of the surface which resists further attack, while hydrofluoric acid forms a protective film which rapidly brings reaction to an end. Magnesium is inert to alkalies, due to the formation of protective films, and thus is directly opposite from aluminum. Chloride ions are able to penetrate protective films and lead to corrosion. Protection is afforded by alloying with less susceptible metals as manganese and zirconium, chemical or electrochemical treatment and erection of physical barriers as paint, rubber sprays, etc. Chemical treatment by means of chromate, fluoride, phosphate or carbonate dips is described. The disadvantages and advantages of each of these protective means is discussed. To give galvanic protection, steel or brass parts should be cadmium or zinc plated before joining to magnesium and "wet assembled" with chromate solutions.—INCO.

6.4.4. 3.5.8

The Extrusion of Powdered Magnesium Alloys. R. S. Busk and T. E. Leontis. *Trans. Am. Inst. Mining Met. Engrs.* **188**, 297-306 (1950) Feb.

Direct extrusion of magnesium-alloy powder is described. It was used to produce four new magnesium-alloy types by controlled solid-state diffusion. The importance of the use of atomized powder, a new mechanism termed "interference hardening," a method for combatting stress corrosion and a method for increasing the hot-short speed of extrusions are also discussed.—BLR.

6.5 Metals Multiple or Combined

6.5

Less Common Metals. D. B. Broughton. *Ind. and Eng. Chem.*, **42**, 2023-205 (1950) Oct.

Reviews literature of past year on titanium, zirconium, tantalum and the noble metals.—BLR.

6.6 Non-Metallic Materials

6.6.8, 8.9.5

Navigational Aids Use Phenolics. *British Plastics*, **23**, No. 256, 83-85 (1950) Sept.

Highly sensitive instruments now used in navigational aids incorporate many components which can be successfully and economically produced as moldings from phenolic materials. The main reason for this is that these components have intricate shapes and must maintain good electrical insulation under all climatic conditions. In the maritime gyrocompass, for example, the windows of the repeater dials on the bridge of a ship, which indicate the reading of the master gyrocompass below, are molded in phenolic. Such an item would be hard to machine from metal or wood. The Gyrosyn compass, as well as other instruments used on ships and planes, also use many phenolic components.—TDB.

6.6.8, 8.8.1

Chemical Plant in Rigid P.V.C. *Brit. Plastics*, **23**, No. 256, 80-82 (1950) Sept.

The special properties of unplasticized, or rigid, polyvinyl chloride — its long life, resistance to corrosion, light weight, price and ease of fabrication — are contributory factors which will continue to expand the applications of this material for specialized purposes such as the construction of anti-corrosion equipment in industrial plants. This article describes some of the specific application of polyvinyl chloride in the manufacture of chemical tanks, ducting, valves and valve components. Methods of handling sheet, rod and tube forms of this material are also described.— TDD.

6.6.6

Detergent Reduces Etching of Bottles by Caustic. *Chem. Ind.*, **67**, No. 5, 759 (1950) Nov.

Laboratory tests with Nytron showed that it possesses the property of reducing substantially, corrosive attack of straight caustic soda solutions on glass surfaces. Results indicate the reduction of corrosion wherever glass or ceramic surfaces are in contact with alkaline solutions. Tests showed weight loss of typical Coca-Cola bottles due to caustic soda attack about 14 times less with Nytron in the caustic solution. Weight loss due to corrosion of glass microscope slides was reduced about 210 times compared to weight loss of test slides in a caustic solution not containing Nytron.—INCO.

6.6.8

Low-Temperature Potentialities of the Silicone Rubbers. *Nat. Bur. Standards, Tech. News Bull*, 107-108 (1950) Aug.

A recent investigation at the National Bureau of Standards has shown that the silicone rubbers, developed especially for high-temperature applications, have better potentialities for use at extremely low temperatures than any synthetic or natural rubber studied thus far. This conclusion is based primarily on measurements of the second-order transition temperature of the silicone rubbers. The silicones are synthetic rubbers in which some of the carbon atoms normally present are replaced by silicone and oxygen. Since these materials are highly resistant to heat, retaining their elasticity and electrical resistance at temperatures as high as $200°$ C, they have been found especially well suited for hose and gaskets in airplane engines and for insulated cables.—TDD.

6.6.8

Radome Construction With Low-Pressure Resins. G. May. *Plastics* (London), **15**, No. 161, 265-268 (1950), Oct.-Nov.-Dec.

The use of "low-pressure" or "contact" resins in the construction of radomes for Lancaster aircraft and for auxiliary fuel tanks for Mosquito bombers is described. The properties of these resins designated CR 39, Perspex and Nuron 100 are discussed, and a description is given of the methods of construction and laminates employed. The problems encountered in the molding process of the various radomes are outlined and explained by means of several drawings.—TDD.

6.6.11

Corrosion Damage From Wood-Impregnating Agents and Attack of the

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Corrosion Products on Impregnated Wood. (In German.) F. Moll. *Werkstoffe u. Korrosion*, **1**, 169-170 (1950) May.

A brief discussion.—BLR.

6.6.8

Stress Cracking of Polyethylene. R. H. Carey, Union Carbide and Carbon Corp. *ASTM Bull*. No. 167, 56-60 (1950) July.

The effects of some environments upon the tensile properties of polyethylene are reported. It is found that tension specimens containing a small hole break at stresses and elongations less than those normally reported. This change in mechanical properties is greatly accentuated by fluids such as alcohols and toluene. This phenomenon is compared to "stress-corrosion cracking" as observed in metals where cracking occurs in mildly corrosive environments. Data are reported for a wide range of molecular weight polyethylene resins and the effects of environment are found to decrease with increasing molecular weight of the resin. The data permit quantitative comparison of the cracking resistance of different resins. The properties of polyethylene are compared with older more common materials. It is shown that polyethylene is not a "rubber-like" or "elastomeric" material, but more nearly resembles some non-ferrous metals. This comparison is inferred from its crystalline structure, stress-strain diagram, and "stress-corrosion cracking" phenomenon.—TDD

6.6.11, 3.3.4, 4.6.4

Fundamental Principles Leading to an Understanding of Wood Deterioration. D. R. Baker. *Industry and Power*, **59**, 94-97 (1950) Sept.; 86-88 (1950) Oct.

Refers principally to deterioration of wood in cooling towers. Research results indicate that plant growths, such as fungi and mosses, change physical and chemical structure of the wood.—BLR.

6.6, 7.5

The Preservation of Timber by Chemical Treatment at McIntyre. D. E. Keeley. *Can. Mining Met. Bull.*, **42**, 606-617 (1949) Nov.

Untreated timber used for posts and caps 3875 feet underground decayed in 3 or 4 years, but since the installation of a treating plant in 1934, no treated timber has rotted away. The solution used was formerly 4.5 percent zinc chloride, but this has recently been replaced by 4.5 percent chromated zinc chloride solution. After a period at a reduced pressure, the timber is submerged in the preservative at 160 degrees and at a pressure of 150 lb. per sq. in. A further 30 minutes at reduced pressure helps to prevent excessive bleeding of the preservative. Corrosion of the steel treating-tank was prevented by the addition of a small quantity of creosote to the preservative solution. The zinc chloride also very considerably reduces the fire risk.—ZDA.

6.6, 1.3, 3.3

Microbiological Degradation of Cellulose. Glenn A. Greathouse. *Textile Research J.*, **1950**, Apr. 20. 227-238.

Reviews, correlates, and discusses literature on the above. 71 ref.—BLR.

6.6

Carbon and Graphite as Materials of Construction. (In German) E. Franke. *Werkstoffe u. Korrosion*, **1**, No. 6 and 7, 254-260 (1950) June, July.

Includes tables of the physical properties of various forms of carbon and graphite having different pore sizes, and of their corrosion behavior towards numerous oxide and acid mixtures; salt solutions, gases and organic solvents.— BNF.

6.6

A Test of Treated Timbers in a Mine at Negaunee, Mich. F. S. Crawford and R. M. Wirka. Bureau of Mines, Rep. 4622 (1950) Jan. U. S. Dept. of the Interior.

This investigation compared the average useful lives of timbers treated with zinc chloride (13.3 year), borax (11.2 year), or sodium fluoride (7.7 year) with those of untreated timbers (3.8 year). The relatively poor results obtained with borax and sodium fluoride were partly due to inadequate absorption of the preservative by the timber. A comparison of costs showed that the use of zinc chloride-treated timbers resulted in a saving of 55 percent over that of untreated timbers.—ZDA.

6.6.11, 3.4.9

Corrosion of Metal Fastenings in Zinc Chloride-Treated Wood After 20 Years. R. H. Baechler. *Proc. Am. Wood-Preservers' Assoc.*, **45**, 390-397 (1949).

The tests showed that moisture is the controlling factor in the corrosion of fastenings in ponderosa pine treated with zinc chloride, just as it is in untreated wood. The zinc chloride preservative only accelerated corrosion under conditions of high humidity (90 percent). Galvanized nails showed no serious attack during the 20 year period except in wood treated with a 2 to 1 mixture of zinc chloride and sodium dichromate and exposed to 90 percent relative humidity. Brass screws underwent some dezincification at this high humidity.— ZDA.

6.7 Duplex Materials

6.7, 3.4, 3.5

ONR Conference on Physics and Chemistry at High Temperatures. J. H. Lawser, Temple Univ. Paper before ONR Conf., Philadelphia, Apr. 25, 1950. *Science*, **III**, No. 2891, 584-585 (1950) May 26.

Oxidation studies on cermets was reported at the Office of Naval Research conference by V. B. Crandall of Alfred University. The systems studied were binary alloys of nickel, cobalt, iron, aluminum, and beryllium with chrysoberyl magnesium oxide, zinc oxide. The oxidation behavior may be explained by considering the rate at which oxygen is removed from the pores by oxidation of the metal. It is indicated that there may be applications of these materials for high temperature—high stress work if the oxidation rates of the metal components can be controlled.—INCO.

6.7

Refractory and Wear-Resistant Parts Made From New Silicon Carbide Material. *Steel*, **127**, 91-92 (1950) Aug. 14. Based on paper by C. G. Rose.

Describes versatile new refractory

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material composed of a dense network of silicon carbide imbedded in a matrix of silicon which may find wide use in refractory, electrical conductivity, or corrosion-resistant applications.—BLR.

6.7, 4.7, 3.5

Metal-Ceramic Has Combination Properties. *Prod. Eng.*, 21, No. 6, 168 (1950) June.

Metamic LT-1, 70 aluminum-oxide ceramic and 30 powdered chromium, has increased thermal conductivity and shock resistance by the metal, while the ceramic resists high stress, high-temperature deformation and affords good resistance to molten brass and bronze. The new ceramic is only superficially attacked by molten steel and furnace slag. It is resistant to combustion gases up to 3,100 degrees F and to oxidation at 2,200 degrees F in air. Argon and nitrogen were injected into carbon and stainless steels with the material but it is unsatisfactory for injecting oxygen into molten steel. It is superior to most ceramics in the thermal shock resistance. The new products are fabricated by powder metallurgy techniques and cannot be worked by rolling, forging or drawing.—INCO.

7. EQUIPMENT

7.1 Engines, Bearings, Turbines

7.1, 2.3

Silver Surfacing Improves Performance of Gas Turbine Roller Bearings. Donald F. Wilcock and Frederick C. Jones, General Electric Co., Thomson Laboratory, Lynn, Mass. *Steel*, 125, 61-63 (1949). Also presented at the National Meeting of the American Society of Lubrication Engineers held at New York City, April, 1949.

Examination of high-speed, high-temperature bearings removed from turbine engines revealed that the principal source of trouble lies not in the steel races or the steel rollers, but in the roller separator and retainer. Bearings which failed in special engine tests had a large amount of brass smeared on the working parts and the brass retainers had usually been broken by the welding of this transferred material to them. Elecroplating the retainers with one of several metals and alloys, particularly silver, greatly increased their operating life and reduced metal transfer between poorly lubricated surfaces.

All-brass bearings could be operated without difficulty at high speed when lubricated with a continuous jet of oil. When the bearings were operated dry the separator was demolished in a few seconds or a few minutes. Designs in which the separator is guided by the rolls rather than by the inner race may be better when lubrication is poor, especially if improved separator materials are used.

Silver plating did not improve separator performance when new bearings were tested dry. When run in with oil for 5 minutes before dry testing, silver-plated separators average 6 minutes and unplated brass separators only 3 minutes of operation before failure.

When the lubricant was removed by heating the bearings until almost all the oil vaporized and only a slight varnish film was left behind, bearings with brass separators averaged 3.8 minutes before failure, as compared with only 3 minutes when the lubricant was removed with solvents. Bearings with silver-plated separators operated 292 minutes under these conditions.

Chromium plate was found to be too hard. Silver-lead-indium, lead-tin-copper and tin-copper plates tended to form numerous tiny bubbles on the surface after the high-temperature runs, but the base brass was still tinned beneath these bubbles. Tin-copper plate was considerably inferior to the others, but still better than brass alone.

In conducting the tests there were five operating conditions, viz., steady lubrication, multiple starts, delayed lubrication starts, baked oil operation and dry operation.—PDA.

7.1, 6.6, 6.7

The Applicability of Ceramics and Ceramals as Turbine-Blade Materials for the Newer Aircraft Power Plants. A. R. Bobrowsky. *Trans. ASME*, 71, No. 6, 621-629 (1949).—MI.

7.1, 3.5

Gas Turbines, High Temperatures and High-Strength Steels. (Turbine a Gas-Acciai per alta resistenza ad elevate temperature). *Iron and Steel*, 23, No. 3, 85-87 (1950) March.—MI.

7.1, 3.5

Effect of Grain Size of Quartz Dust on Wear Resistance of Different Pairs of Materials. (In German.) Karl Wellinger. *Z. Ver. deut. Ing.*, 92, 371-375 (1950) May 21.

Above study was made to determine the possible necessity of eliminating even the smallest dust particles from the air entering internal-combustion engines. Results show that rate of wear depends on the metal pairs present in cylinder and piston or piston ring, respectively; and that below particle sizes of 40 μ microns, rate of wear drops rapidly with particle size. Photomicrographs, diagrams, tables and graphs.—BLR.

7.1

The Selection of Bearing Materials. Arthur F. Underwood. Sleeve Bearing Materials, ASM, 210-222 (1949).

The requirements of a good bearing material are discussed, score resistance, compressive strength, fatigue strength, deformability, corrosion-resistance and structure being considered in detail. Methods of measuring these properties are also discussed. The mechanical properties of a number of typical bearing materials are given. 11 references.—MA.

7.1

Al-Fin Bonds Aluminum to Steel and Iron. R. E. Stockwell. *Avia. Ops.*, 19; illus. (1950) July.

The versatility of the Al-Fin bonding process is discussed. This bonding process affords a foolproof joining between steel and aluminum, permitting thicker sections of the second metal to be bonded than is possible by the plating methods. In the Al-Fin technique the ferrous component is immersed in an aluminum bonding bath that has been heated to 1200°-1205°F. Once the steel or cast iron becomes miscible with the aluminum, it forms an intermetallic compound consisting of aluminum and iron. Withdrawn from the bath, the part is placed in the desired mold and an aluminum casting alloy is poured around it. The poured aluminum fuses with the molten aluminum on the ferrous piece. The result is a bond with a strength of 15,000 psi and a shear value of 7000 psi. Because of its excellent heat-dissipating qualities, aluminum formed into fins makes an ideal metal to use on the nonwearing surfaces of brake drums. The latest use of the Al-Fin process is in coating jet-engine combustion chambers, inside and out, thereby increasing the life of the chambers. Aluminum-coated chambers show none of the scaling or powdering common to steel chambers.—TDD.
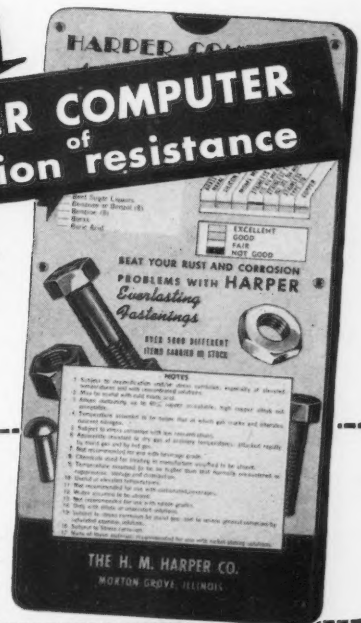
7.1

Corrosion of Diesel Cylinder Liners. R. N. Speller and F. L. LaQue. *Railway Mech. and Elec. Eng.*, **124**, 258-261 (1950) May.

A condensation. Describes and illustrates peculiar type of attack frequently encountered on the water side of the above. Experiments indicate its cause to be cavitation-erosion caused by high-frequency vibration. However, an element of electrochemical corrosion apparently exists, since chromate inhibitors and use of austenitic cast iron (Ni-resist) are somewhat effective in service, although not in laboratory testing where pure cavitation-erosion can be produced. Recommends practical steps for minimizing attack. Also discusses ordinary corrosion of Diesel liners and its prevention.—BLR.

7.1, 5.3

Chromium-plated Piston Rings. *Gas Oil Power*, **44**, 370-371 (1949) Dec.

Chromium has long been known to be extremely wear- and corrosion-resistant and the plating of wearing parts in internal-combustion engines is by no means new and has proved successful. However, its success in this field has always been hampered by the problem of maintaining an oil film on the surface, difficulties of processing and accurate sizing, and of relatively high cost. In developing chromium-plated rings there have been many difficulties to overcome. In the first place, the problems of adhesion between cast iron and chromium presented — as the liner-plating specialists found before the war—a multitude of difficulties which have now been solved. The next difficulty was to avoid sharp ragged edges at the corners of the rings, and the standard procedure now is to use a small chamfer before plating; this has entirely solved the problem. The next troubles were found in operation where, because the chromium is so wear resistant, it takes a very long period to bed into the cylinder. To overcome this, small diameter rings are manufactured with a tapered periphery of ½ deg. to 1 deg., and are lightly lapped in a dummy cylinder to establish a narrow land of contact around the full circumference. These rings rapidly bed into the cylinder and at the same time establish immediate oil control. For the larger diameter rings, such as are used in Diesel engines, taper turning is not practicable and alternative means are being used quite effectively. Chromium-plated rings are now in regular production for many types of engines and are standard fitment by a number of makers with engines up to 8½-inch bore size. The employment of such rings in engines of appreciably larger cylinder bore is new, but progress is being made.—TIME.

7.1, 5.3

Application of Radioactive Tracers to Improvement of Automotive Fuels, Lubricants and Engines. P. L. Pinotti, D. E. Hull and E. J. McLaughlin. Soc. Automotive Eng., New York, Preprint 304A. *SAE Journal*, **57**, No. 6, 52-54, illus., tables, diagrs. (1949) June. (Also published in: *Petro. Eng.*, **21**, No. 6: C5-C8 under title: Radioactive tracers used in research on engine wear.)

A radioactive tracer technique is superior to conventional engine wear tests with respect to length of testing time, cost, accuracy, and ease of performance. With proper safety precautions, the radioactivity is not a hazard.

The rate of wear increases consistently with increased sulfur content of fuel, in agreement with published information.

The amount of radioactive material removed from the engine part under study and present in the lubricating oil is determined with a Geiger counter. The top compression ring was selected for initial study because the condition of this part of the engine has an important influence on engine operation and also because the wear on the cylinder wall is usually a function of the wear of the top ring. Ordinary cast iron piston rings made radioactive by neutron bombardment in an atomic pile are installed in the top ring groove. After a short break-in period to establish uniform conditions, the crankcase is flushed and charged with fresh oil of known background activity. At intervals during operation under the desired conditions oil samples are removed and their radioactivity measured by immersing the Geiger counter in them for a few minutes. The measured sample is returned to the crankcase. This method, developed on a standard, single-cylinder, 4-¼ in.-bore, four-cycle Diesel engine makes possible the detection in the lubricating oil of as little as 0.1 ppm iron from the radioactive part. The radioactive composition is uniform, i.e., the isotope ratio is constant throughout each ring and from one piston ring to another in any group irradiated at one time.

Precautions taken to keep body exposure to radiation below the safe tolerance level (100 milliroentgens per day) included handling the radioactive parts with a set of long tongs and tools and the wearing of exposure meters by all personnel working near the isolated research project.—PDA.

7.1

Corrosion in Gas Turbines. *Motor Ship*, **31**, 124 (1950) July.

Editorial comment on difficulties associated with vanadium pentoxide corrosion at the high temperatures involved in gas-turbine operation. Lower temperatures operative in Diesel engines partially explain absence of such effects in Diesels, and it is suggested that there may be some truth in the suggestion that vanadium does not give rise to any trouble in presence of very minute amounts of carbon, such as are present in the Diesel combustion process. Urged that there must be a clear understanding that boiler oil of the usual boiler-oil viscosity, and purchased at boiler-oil prices, cannot be used for operation of gas turbines. Much higher grade of fuel is essential. The implications of this fact and of the vanadium-oxide corrosion problem require consideration in relation to future commercial economic development of gas turbines.—INCO.

7.1, 1.7, 3.5

Admiralty Work on Heavy Fuels. *Oil Engine and Gas Turbine*, **18**, 14 (1950) May.

Collaborating with NGTE, Admiralty has undertaken extensive study of heavy fuel burning. Work on fuel characteristics (ash-forming constituents and their removal before combustion), atomization, combustion chambers, heat transfer, blade and heat-exchanger tube fouling, materials (effect of sulfur, sodium and vanadium compounds on high temperature materials), is discussed. Gas-turbine activities at Admiralty Engineering Lab. include running of Metrovick axial-flow aircraft-type gas turbine, and work on

combustion-test rig (data on oxidation rate of various blade materials in combustion products of kerosene).—INCO.

7.1, 6.6

How to Be Happy with Teflon Packing. E. C. Fetter. *Chem. Eng.*, **57**, No. 7, 229-230 + (1950) July.

Compounded Teflon is a packing to be used in rotating shafts. It is composed of very thin shreds of oriented Teflon fibers so that it has low frictional properties and is corrosion resistant. It is not adversely affected by high peripheral shaft speeds and will seal without shaft wear or overheating. Precision fitting and careful run-in are essential to avoid wear and corrosion. The use of Teflon in pumps, agitators and autoclaves and solid Teflon gaskets are described.—INCO.

7.1

Why Do Bearings Fail? Factors Responsible for the Short Life of Bearings. Ramon Larre. *Metalurgia y Elect.*, 13, No. 147, 21-23 (1949).

Bearings fail through wear, errors in adjustment, inadequate load distribution, bad alignment, incorrect allowance for oil film, defective lubrication, fatigue, overload, corrosion, extraneous materials on the bearing surface and manufacturing defects. Some illustrated examples are given of bearing failures and their causes.—MA.

7.1

Why Engine Bearings Fail: 1. Improper Installation; 2. Poor Operation; 3. Faulty Manufacture. *SAE Journal*, 58, 44-47 (1950) June. Based on "Engine Bearings, Construction and Performance," by W. E. Thill.

Describes and illustrates fatigue and wear. Materials mentioned are cast iron, steel, and copper, tin and cadmium-base alloys.—BLR.

7.1

Investigations on Cylinder-Liner Wear. W. G. Payne and W. F. Joachim. *SAE Trans.*, 1949, Jan. 51-68.

A group of 24 engines was selected for an investigation of the causes of cylinder-liner wear. Engine factors found to have a pronounced influence on cylinder wear included bore size, piston speed, cylinder displacement, brake mean effective pressure, liner hardness, piston-skirt clearance, fuel consumption, lubricating oil consumption, lubricating oil temperature and cooling water temperature. Attempted correlation of the wear and surface failure data with present theories of wear strongly indicated the presence of a type of wear not previously discussed: a wear of the surface caused by separation of very fine particles or a general surface disintegration.—GPC.

7.1

Jets Test Designers and Metallurgists Ingenuity. R. B. Johnson. General Electric Co. *Iron Age*, **166**, No. 6, 73-78 (1950) Aug. 10.

The performance of various materials applied to different components of the jet engine is discussed. Materials of increased thermal conductivity do not represent a solution to the problem of combustion-chamber liner material. Ceramic coating of the metal liner has not been particularly helpful, unless the coating is quite thick. An increase of wall thickness has added increased life and strength to the liner, but the additional weight is not desirable. A number of

new alloys, heat-treatment and special processing have been developed to solve the problem of combustion-chamber liner construction. Vitallium has been found the best material for manufacture of diaphragm partition materials. A number of tests were undertaken to determine optimum performance of three turbine buckets.—TDD.

7.1, 5.8.2, 5.4.5

Corrosion Protection of Machine Parts and of Surfaces Cooled by Circulation of Water in the Motors. M. E. Antinori. Bolletino Technico Fiat Grandi Motori No. 2 (1950); *Abstr. Genie Civil* 127, 457 (1950) Dec. 1.

Two series of tests on corrosion protection are reported one of which was on metallic or varnish-type protective coatings, and the other on corrosion inhibitors added to the circulating water of the engines. Best results in this second series were obtained with a mixture of potassium bichromate and sodium carbonate. Resin coatings of the type used in hot humid climates during the war were also promising.

7.1, 2.3.6

Heat Shading of Metals Aids Gas Turbine Research. *Avia. Ops.* 1950, 26, Aug.

The color of the thin oxide film that forms on hot metal and remains after the metal has cooled is being used to study the maximum operating temperatures reached in gas-turbine engines. Oxide films on the turbine parts are compared with the color of the film in samples that were heated and cooled under controlled laboratory conditions. The analysis system is not as simple as it sounds, since each alloy has its own heat-shading characteristics and cannot be used for comparison with other alloys. Furthermore, the heat-shaded sample and the engine part must be approximately the same size and shape and the sample must be heated under conditions simulating engine operation. A specific test run is described, and it is pointed out that this analysis method finds the best application in the 900° to 1500° F range.—TDD.

7.2 Valves, Pipes and Meters

7.2

The Problem of Materials for Marine Gas Turbines. *Metallurgia,* 42, No. 248, 1-2 (1950) June.

It was shown both with ash produced by the combustion of vanadium-bearing fuel oils and with synthetic ash consisting of vanadium pentoxide V_2O_5 and Sodium Sulfate, that in its molten state the ash rapidly attacks all the well known gas turbine steels and alloys. The higher the temperature, the greater is the rate of attack. The possibilities of protective coatings have so far proved disappointing.—INCO.

7.2, 6.2

Deterioration of Cast-Iron and Spun-Iron Pipes. J. C. Hudson. *Iron & Coal Trades Rev.*, 160, No. 4294, 1443-1444 (1950).—MI.

7.2, 5.4

Corrosion. M. G. Fontana. *Ind. Eng. Chem.*, 42, No. 5, 65A-66A (1950) May.

A new type plug valve has a solid Teflon liner and is presently available in Durimet 20. The advantages of the valve are that it requires no lubrication, has no metal-to-metal contact, is free from seizing and galling and there is no lapping of plug and body The high plug-to-liner pressure prevents foreign material from getting inside the liner, ensures a tight valve pressure up to 150 psi and prevents sticking. The Teflon liner is a corrosion resistant thermoplastic inert to practically all chemicals and solvents. It is available as a suspensoid spray as well as in sheets.—INCO.

7.2, 8.4, 3.2

Corrosion of Relief Valves in Sour-Crude Service. R. J. Hafsten, S.O. Co. Ind. Preprint, API 15th Mid-Year Meet, Cleveland (1950) May 2.

Methods of preventing the corrosion and subsequent failure of refinery relief valves exposed to hydrogen sulfide from sour crude processing were developed. The breakage of relief valve springs was shown to result from hydrogen embrittlement resulting from the migration into the spring of atomic hydrogen evolved during iron sulfide formation at the metal surface. Metallizing the springs with aluminum eliminated the failures. Corrosion of 17-20 percent chromium steel disc guides was serious because the build up of corrosion products prevented the valves from functioning effectively. Electroplating the disc guides with 0.002 to 0.003-inch of hard chromium was a satisfactory solution. Relief valve nozzles and springs made of 18 percent nickel, 8 percent chromium steel were found to be very susceptible to intergranular corrosion when exposed to high hydrogen sulfide concentrations at

900 degrees F. However, the problem was solved by using 18 percent chromium, 8 percent nickel-steel discs and guides.

7.2, 8.4

Sheet, Steel and Spun Aluminum Team Up with Studweld Design to Make Petroleum Tank Vent Valves Convenient to Handle and Easy to Install. C. Stewart. *Steel,* **126,** No. 12, 83 (1950) Mar. 20.

7.2, 6.2, 1.3

Interim Report of the Departmental Committee on the Deterioration of Cast Iron and Spun (Centrifugally-Cast) Iron Pipes, Ministry of Health. Brochure, 1950. HMSO.

Report on the underground corrosion of water mains: statistics and financial aspects; manufacture of pipe; pipe sizes and joints; construction of mains; microbiological and other corrosion processes; factors influencing corrosion; corrosion prevention; conclusions and recommendations; select bibliography. A geological map showing potentially corrosive formations in England and Wales is included. Reference is also made to a bibliography (Corrosion of Metal Structures Buried in Soil) prepared by the British Cast Iron Research Association; this is available as BNF Serial 34,122. It contains 480 references mainly concerning cast iron pipes and only including those papers dealing with non-ferrous materials (pipes, protective coatings, anodes, etc.) which have some bearing upon the main interest.—BNF.

7.2, 6.4

Aluminum Pipe Lines. W. B. Moore, Reynolds Metals Co. *Welding Eng.,* **1950,** July 26-29.

Aluminum pipe lines are being used to transport oil, natural gas and other fluids generally carried in steel lines. Comparative costs show a considerable saving for the aluminum installation, though its first material cost is higher. Advantages are: Light weight of aluminum simplifies handling problems; reduced fluid friction; savings on overhead and aerial river crossings; corrosion resistance makes it unnecessary to wrap pipe and aluminum scrap has high recovery value.—TDD.

7.2, 4.6, 5.4

Creole-Shell Siburua Water Line Is Coated Inside by New Method. R. L. Buck, Williams Bros. Co. *Oil Gas J.,* **49,** No. 3, 114 + (1950) May 25.

Steel piping used to convey the water supply to the Shell Refineries in Venezuela have an inside coating of hot pipe-line enamel. It is possible to enamel the tie-in welds in the field. The pipe is 30 and 34 inches in diameter. Data on the method of application are given. The outside of the pipe is unprotected except when it is in areas exposed to salt spray. It is then covered with cold pipe-line enamel. Photographs.—INCO.

7.2, 5.4.5, 1.7.1, 4.5.1

Report of the Corrosion Commission II for the Study of the Effects of Soil on Pipes. Centraal Instituut Voor Materiaalonderzoek, Afd. Corrosie Mededeling, No. 13, 75 pp (1949).

Detailed discussion of the experimental methods used for the coating of cast-iron and steel pipes with blown asphalt bitumens. External and internal protection of pipes and the requirements of asphalting are reviewed. The methods for pretreatment of the pipes, their

transport and installation and the assessment of the results are described.—RPI.

7.2, 6.6.8, 8.9.2

Water Pump Plastic Impeller. *Automotive and Aviation Inds.,* **102,** No. 6, 214+ (1950) March 15.

Reason for the adoption of a molded phenolic water pump impeller by Cadillac for its 1950 engines, is that the molding is made accurately to size and shape, thus eliminating the previous problems of machining and balancing malleable iron impellers. Molding is produced with an excellent surface finish which has a salutary effect on water pump efficiency. It gives satisfactory service under high pressures, high temperatures and with anti-freeze mixtures. Compared with cast metal impellers, the plastic ones permit a weight saving of about 81 percent.—MA.

7.2, 8.2.2

Metal Spraying of Power-Station Water Pipes. *Brit. Ind. Finishing,* **3,** No. 26, 71-72 (1950).

A description of the shot-blasting, zinc spraying and painting of power-station water pipes.—MA.

7.3 Pumps, Compressors, Propellers, Impellers

7.3, 8.10, 6.5

Deep-Well Pumps and Shaft Pumps in Anthracite Mines of Pennsylvania. W. H. Lesser. U. S. Dept. Interior, Bur. of Mines, RI 4656, 52 pp (1950) Mar.

Purpose of the report is to furnish data concerning application, design, and performance of deep-well and shaft pumps to the Anthracite Flood-Prevention Project for consideration when a pumping project develops that favors the use of these pumps. Report includes a study of pump design, descriptions of deep-well and shaft pumps in the anthracite area, performance records, data concerning their dependability, estimate of installation costs and the general acceptance of them by mine managers. Metal used in pump parts are: Zincless bronze, SAE 63, or chromium-nickel alloy casings; bronze, stainless steel, or chromium-nickel alloy impellers; high-carbon steel shafts with the exception of the lower section which is preferably made of stainless steel; steel shaft tubing with outside bitumastic covering or wrought iron with outside rubber covering, the lower section being preferably made of stainless steel; steel or wrought iron discharge pipes covered inside and outside with rubber or bitumastic paint and stainless steel bolts and flanges. Selection of metals depends on the acidity of the water to be pumped. 5 references.—INCO.

7.3, 6.4, 5.10

Overlaying with Aluminum-Bronze Electrodes. J. A. Cunningham. *Welding J.,* **28,** 1162-1165 (1949) Dec.

Where metal-to-metal contact is involved, hard grades of aluminum-bronze electrodes (160 to 300 Brinell) are rapidly assuming an important place in overlaying new and worn steel parts because they provide low-friction, nonseizing surfaces and wear remarkably well. Further, aluminum-bronze electrodes can be applied to high-carbon, alloy or tool steel without danger of

spalling off or cracking the parent metal. Most grades of cast iron and bronze can also be overlayed. Overlays are successful on difficult-to-weld metals such as large tool steel, medium carbon or cast-iron gears, because bronze inherently possesses a characteristic of penetrating into the pores of the metal and bonding firmly. Also, since aluminum bronze melts at approximately 1,950 degrees F, 700 degrees less than steel, it can be applied rapidly without materially affecting the heat treatment in the parent metal and the deposit feathers out as welded and leaves no craters when the arc is broken. Much of the long wearing characteristics of aluminum bronze can be attributed to the high polish attained by the bronze as it wears. Excellent life is obtained even when the bronze overlay is working against hardened steel parts due to the non-seizing effect of dissimilar metals working against each other. Bronze overlaid shafts operating against pump packing last three to six times longer than the original shafting which is usually harder than the bronze overlay. It is interesting to note also that packing life is tremendously increased when shafts are overlayed with hard aluminum bronze because bronze wears smoothly and does not pit or corrode. When shafts are to be operated against bronze bearings, bronze overlays are not recommended because the dissimilar metal effect would not be present.—TIME.

7.4 Heat Exchangers

7.4, 6.3, 4.6

Nickel-Copper Alloy Shows Marked Corrosion Resistance. G. A. Mills, Central Power & Light Co., Corpus Christi. *Elec. World,* **133,** No. 19, 113 (1950) May 8.
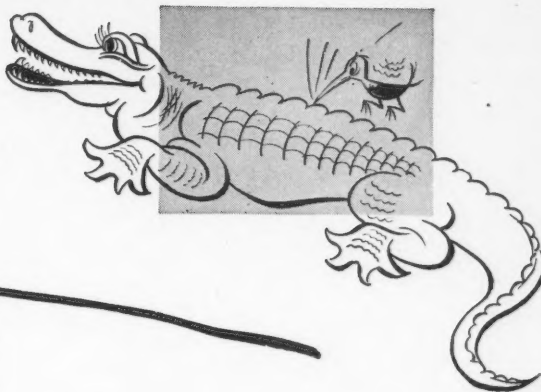
Tests for 21½ months show that heat-exchanger tubes of nickel-copper alloy 754 (9.69 nickel, 89.21 zinc, 0.004 lead, 0.80 iron, 0.12 manganese) have marked resistance to sea water corrosion. Alloy 701 (29.72 nickel, 69.99 copper, 0.07 iron, 0.22 manganese) and Alloy 702 (29.95 nickel, 68.05 copper, 0.45 iron, 1.25 manganese, 0.30 zinc) were less resistant.—INCO.

7.4.2, 5.9.3

The Mechanical Cleaning of Fouled Heat Exchanger Tubes. A. John. *Trans. Am. Soc. Mech. Engrs.,* **71,** 825-829 (1949) Oct.

Causes of fouling include: 1) localized high temperatures, 2) precipitation of solids at sharp rise or fall of temperature, 3) low velocities of fluids, 4) cutting units off stream, 5) congealing reaction of certain fluids. Preventive maintenance, including a regular cleaning schedule, is important in the control of fouling. Scale types range from flint hard to soft gummy, with many chemical compositions and algaes. The use of variable-speed, air or water driven tube cleaners of varieties to fit the hardness of scale and extent of fouling is discussed. The flow of air and water through hollow driving tube is necessary to scavenge cuttings of fouled matter. Flexible shaft electrically driven drills are useful for confined quarters and for vertical open type shell and tube refrigeration condensers, without taking the latter out of service during cleaning. Turbine type insertion cutters, air, water

or steam driven cleaners are popular and successful in boiler rooms.—RA.

7.5 Containers

7.5, 4.6
Galvanizing Water Tanks at Hotpoint. J. Wallerius. *Iron Age,* 165, No. 24, 110-112 (1959) June 15.

Accurate control of cleaning and fluxing operations and of galvanizing is important for corrosion resistance. Furnace design and head distribution characteristics critically affect surface finish.—BNF.

7.5, 8.3, 3.6, 5.4
Corrosion of Enameled Tin-Plate Covers on Glass Containers. Edward F. Kohman. *Ind. Eng. Chem.,* 42, 1578-1581 (1950) Aug.

As manufacturers of strained baby foods shifted from the use of cans to glass containers, perforation corrosion of the covers occurred more often, regardless of the weight of the tin coat on the jar covers. This indicated a heretofore unrecognized corrosion factor. The data presented explain the mechanism which involves the ability of the seal to conduct an electric current. Consequently a galvanic couple is set up with metal exposed on the inside of the jar as the anode and metal exposed outside the jar as the cathode. Corrective measures are suggested.—BLR.

7.5, 5.2, 3.2, 3.5
Corrosion Mitigation Within Dehydrating Tanks—TP 2847. E. O. Kartinen, Signal Oil & Gas Co. Paper before AIME, Petroleum Branch, Los Angeles, Oct. 20-21, 1949. *J. Petro. Tech.,* 2, *Petroleum Trans.,* 189, 175-178 (1950) June.

The type of corrosion considered is that which occurs in the water-exposed areas of dehydrating tanks and to a lesser degree in some stock tanks. Operating temperature of these waters varies from 80 degrees-160 degrees F and the salt counts run from a few thousand to as high as 25,000 parts per million. Corrosion in these tanks occurs in form of pits, ringworm type of attack along the vertical and horizontal bolt seams and as a general attack spread over a wide area. Cathodic protection is a satisfactory means of preventing this type of corrosion. Tests and data are given.—INCO.

7.6 Unit Process Equipment

7.6, 4.6
Boiler Corrosion and Feed-Water Treatment. H. Hillier. *Iron & Coal Trades Rev.,* 159, No. 4262, 1184-1185 (1949) Nov. 18.—MI.

7.6, 3.2, 3.5
Localized Formation of Magnetic Iron Oxide in Power Boilers. Steel, Heat and Water. H. M. Rivers and W. M. Sonnett. *Blast Furnace Steel Plant,* 38, 694-696 + (1950) June.

Describes pitting corrosion, attack on a heat-transfer surface by caustic in concentrating film, caustic attack under adherent deposits, hydrogen damage, effects of temperature, and corrosion fatigue.—BLR.

7.6
Localized Formation of Magnetic Iron Oxide in Boilers. H. M. Rivers and

W. M. Sonnett. *Combustion,* 21, 41-46 (1950) June.

A thin film of magnetic iron oxide normally protects boiler metal from spontaneous attack by water. Corrosion occurs if, and only if, the protective film is destroyed. Erosion, sudden temperature changes and other physical or mechanical factors may damage the protective film and permit corrosion. Chemical breakdown of the film may be caused by oxygen, galvanic forces set up by porous or lightly adherent deposits, strong concentration of boiler water caustic or exposure to superheated steam at very high temperature. Any condition that aids these corrosive influences—localized overheating, retarded circulation, steam blanketing, etc.—contributes to the attack. Magnetic iron oxide, produced in proportion to the loss of metal, may remain near the corroded area or deposit elsewhere in the boiler. The hydrogen inevitably released by reaction between water and steel either passes off with the steam or is absorbed by the metal, sometimes causing brittleness and weakness due to intergranular damage. Metal which has failed through overheating, as indicated by changes in microstructure, always shows signs of corrosion, unless a layer of scale has sealed the metal away from direct contact with water or steam.—TIME.

7.6, 3.4, 3.5
Causes and Prevention of Iron Oxide in Boilers. S. T. Powell, L. G. Von Lossberg, and J. K. Rummel. Paper before Midwest Power Conference, April 5, 6, 7. 1950. *Proc. of the Midwest Power Conference,* 12, 133-146 (1950). *Combustion,* 22, 37-44 (1950) July.

Discussion of the nature and concentration of iron oxides in boiler plants, investigation of iron oxide in steam plants, and sources of iron oxide. External corrosion is outlined in regard to carbon dioxide, sodium sulphite, ammonia and related compounds and electrolysis. Listed among the causes of internal boiler corrosion are dissolved oxygen in the feedwater, effects of temperature change, high and low pH values, and hydrogen generation. Copper in boiler water and black oxide production are discussed. It has been found that 12-18 chromium alloy steel rather than mild steel tubes more effectively stand attack from hydrogen formed in the production of ferric-oxide. Boiling out of steam generators with alkaline solutions is listed as a corrective measure as well as ammonia and amine neutralization and recirculation of boiler water. 23 references.—INCO.

7.6.9, 8.8.1
Dowtherm-Heated Finishing Evaporator for Sodium Hydroxide. W. L. Badger and D. J. Pye, Dow Chem. Co. *Chem. Eng. Progress,* 46, No. 10, 486-489 (1950) Oct.

Development of equipment for the evaporation of caustic soda to high concentrations. In the first experiments, a vertical forced-circulation evaporator, having a nickel tube and built of iron and steel, was employed. Iron parts corroded and a vapor head of nickel cast iron and Monel piping was substituted. The problem was taken up by the Dow Chemical Co.; the first experiments being run in nickel beakers. Rapid nickel pickup was apparent. It was found that if atmospheric air were excluded and the caustic was free from chlorate, there

was no attack on nickel. In pilot plant operation, the equipment was an evaporator constructed of nickel where caustic came in contact with metal. The evaporator had a heating surface of seven nickel tubes in a vapor chest of steel pipe. Nickel, heated to a sufficiently high temperature, is attacked even by chlorate free caustic. For this reason the apparatus was jacketed with Dowtherm. Nickel contamination was finally reduced to 1 ppm. Full scale equipment had all parts in contact with caustic made of nickel and a heating surface of 14 gage nickel tubes. The problems encountered in full scale operation are outlined.—INCO.

7.6.4
Care of Idle Boilers. R. B. Conlan. *Southern Power and Ind.,* 68, No. 9, 67 (1950) Sept.

This brief article outlines suggested procedures for both wet and dry layup methods for preventing corrosion in idle boilers.

7.7 Electrical, Telephone, Radio

7.7, 6.3, 5.3
Outdoor Equipment Materials. A. Whittaker. *Mech. World,* 127, No. 3310, 714-715 (1950) June 23.

Another reply to the query about ways of protecting outdoor sub-station equipment against corrosion. The author mentions the use of zinc alloy die castings and other corrosion resistant materials and includes short notes on the four most widely used methods of applying a zinc coating for protecting steel. Phosphate treatments are also mentioned.—ZDA.

7.7, 4.2
Progress Reports on Exposure of Radio Equipment at Tropical Station. U. S. Naval Research Lab. Test Series ONR/TES 17-1; Request Nos. S1374 and S1378. *Prev. Det. Abs.,* 7, E 7 (1949).

The results of tropical tests on four types of naval radio equipment after short periods of tropical exposure are given.—RPI.

7.7
Outdoor Equipment Materials. B. Mc-Evaddy. *Mech. World,* 127, No. 3311, 733-744 (1950) June 30.

This correspondent suggests that corrosion of outdoor electrical substation equipment may be reduced by proper design aimed at preventing the collection of water in pockets. External steel surfaces should be galvanized, and in this case contact between zinc and copper surfaces must be avoided.—ZDA.

7.7, 4.2
Tropicalization of Certain Materials and Parts Used in Construction of Electronic Tubes. (In French.) Georges Trebuchon. *Le Vide,* 5, 748-752; 777-780; 814-818 (1950) Jan., Mar., May.

The "tropicalization"—increase in resistance to hot and humid conditions found in the tropics—of various metals, ceramics, and glasses used in the above was thoroughly investigated. Results are presented in outline form. In the Jan. issue, the problem is stated and the status of present-day specifications given. In the March issue, test procedures are described and discussed. In the May

ssue, methods for protection of the various materials from conditions encountered in the tropics are described and discussed. Includes various types of coatings. 10 references.—BLR.

7.7, 6.4

From a Metallurgist's Notebook: Aluminum Corrosion. H. H. Symonds. *Met. Ind.,* **76,** 189-190 (1950) Mar. 10.

The possibility of corrosion of aluminum-alloy switch boxes by wall plaster was investigated. Results indicate a slight tendency toward such corrosion. Gives recommendations for choice of alloy and surface treatment to prevent it.—BLR.

7.7

Corrosionproof **Electrical Pressure Transmitters.** *Chem. Eng. News,* **28,** No. 20, 1678 (1950) May.

Teledyne electrical pressure transmitters are used with corrosive media as red fuming nitric acid. The instrument produces a full scale output of 50 mv open circuit with linear pressure. It is fully temperature compensated for for zero shift and sensitivity change with temperature. The undamped natural frequency of this transmitter is over 1500 cycles per second, depending on the range.—INCO.

7.7, 3.6, 6.3

Corrosion of Die-Cast Zinc Alloy Conduit Fittings. L. A. J. Lodder. *Metal Ind.,* **76,** No. 13, 249-250 (1950).

Lodder examined the corrosion of die cast zinc alloy conduit fittings in a variety of industrial applications. Exposure tests showed that protective measures are necessary in certain marine and industrial conditions, but that the corrosion at zinc-aluminum junctions is normally far less important than that at steel-malleable iron junctions.—MA.

7.7, 5.2, 3.6, 5.4

Corrosion and Protection of Underground Power Cables. L. J. Gorman. Symposium on Cathodic Protection, Electrochem. Soc. and NACE, 172-184 (1949).

A brief description is given of the component parts of underground power systems, and the principal causes of lead cable-sheath corrosion are given as: 1) stray-current electrolysis, 2) galvanic action, 3) electrolytic cell corrosion resulting from various environmental conditions, and 4) direct chemical attack. The use of duct surveys to explore the condition of the ducts and to locate sections where corrosion is likely to occur is described. The methods of mitigating corrosion which are described are: a) electrolysis drainage, b) cathodic protection, c) protective coatings, d) special cable grease. Magnesium anodes have been used to protect the cables themselves and also to prevent the corrosion of manhole transformers and oil reservoirs submerged in tidewater. The use of aluminum and zinc anodes is also mentioned and there are data on the use of rectifier installations for cathodic protection. Problems arising with submarine cables are also discussed. It is emphasized that the conditions vary widely from one locality to another, and that the choice of a method of protection or a combination of methods must take this into account. Many of the methods described are applicable to communication cables as well as power cables. 15 references are appended.—MA.

7.7, 5.3, 2.3, 3.4

Corrosion of Cadmium and Zinc Coatings in Electrical Equipment. P. T. Gilbert and S. E. Hadden. *J. Electrodepositors' Tech. Soc.,* **25,** 41-49 (1950).

Laboratory tests are described which were designed to determine the behavior of cadmium and zinc coatings at room temperature and 60 degrees C in humid atmospheres in the presence and absence of various insulating materials. It is shown that the rate of attack of cadmium-plated steel in normal humid atmospheres is low, and that for practical purposes cadmium-plated components may be regarded as sufficiently resistant to conditions of high humidity sometimes occurring in electrical apparatus. Under conditions where condensation occurs, rather more attack may be expected on the cadmium, but cadmium would probably be considerably more resistant than zinc under such conditions. Chromating the cadmium plate improves its resistance to attack. The corrosion of cadmium plate may be considerably increased in the presence of moisture and certain insulating materials. A sample of yellow insulating tape which evolved acid vapors was found to be particularly potent in causing corrosion of cadmium, the corrosion product being loosely adherent and containing propionates and butyrates. Vapors of the lower fatty acids were also found to increase considerably the corrosion of the cadmium. A sample of phenol-formaldehyde resin also accelerated attack, but in this case the vapors evolved were alkaline. Zinc coatings (hot-dipped) were shown to be less resistant than cadmium under all the conditions studied. Its corrosion was greatly accelerated in the presence of the insulating materials mentioned.—MA.

7.7, 1.2

An Analysis of the Effect of the Life of Hardware Items of Overhead Pole Line Structures on Overall Annual Costs. E. W. Oesterreich, Duquesne Light Co. *Edison Elec. Inst. Bul.,* **1950,** Aug., 307-319.

In order to analyze the problem of the cost of overhead line supporting structures, the basic characteristics of present-day structures are examined. The examination includes a description of pole-line structures, deterioration factors, reduced first cost of line extension, and wartime operating experience. The analysis is divided into three parts: Analysis of costs for a hypothetical system; example of hardware design possibilities and practical applications to an existing system. It was shown that, while the cost of the hardware is only of secondary importance in controlling total costs, the life of the material items determines the degree of coordination of design, the number of replacements to be made, and the labor and drayage expenditures to be incurred. Data indicate that no method for extending the life of the bolt is as economical as the use of corrosion-resistant material. This is particularly true if the characteristic of corrosion resistance is accompanied by an increase of strength. Among other general conclusions it was found that a reduction in annual costs would be attained if wood pole structures were designed so that all parts of the structure would have a life expectancy as long or longer than the pole. Further, all structures should be rebuilt at time of pole renewal for complete coordination, even though the adoption of this principle requires the replacement of

parts which have been in service for a comparatively short time.—TDD.

7.7

Aluminum-Steel Contact Wires for Trams and Trolley Buses. (A propos des fils de contact en aluminium-acier pour tramways et trolley-bus) L. Albert *Revue de l'Aluminium* (France), **27,** No. 169, 308-312 (1950) Sept.

The inspection of an aluminum-steel contact wire installed in April, 1947, in the Paris suburbs revealed that after 400,000 bus trips the condition of the wire was satisfactory. A greyish coating had formed on parts of the wire but it was not affected by corrosion. The aluminum-steel wire has proved superior to copper wire in resisting short circuits and heating and there has been less tendency to vibrate. An average wear of only 0.01 in. has been caused by the very hard collecting shoes so that the usual life of this type of wire should correspond to 2 million trips while a copper wire is usually worn after fewer than 200,000 trips.—ALL.

7.7, 5.2.1, 2.3.5

Corrosion Testing of Buried Cables. T. J. Maitland. *Corrosion,* **6,** No. 1, 1-6+ (1950).

The corrosion-testing methods employed in connection with tape-armored, jute-protected, thermoplastic-protected, and copper-jacketed buried toll cables are discussed in detail. Examples illustrating the results of corrosion tests and details of the protective measures used to correct unsatisfactory conditions are given.—MA.

7.7, 6.4.2

Aluminum Crossarms. *Materials and Methods,* **32,** No. 4, 70, (1950) Oct.

Aluminum crossarms have been installed on fourteen suspension and seven strain steel transmission towers on the Duquesne Light Company's Phillips-North line near Ambridge, Pa. Approximately 24,000 lb. of aluminum alloy 61S-T6 structural angles were used without any protective coating so that shutdown of the lines for painting was eliminated.—ALL.

7.7, 3.4.9

Investigations Into Tropic Proofing of Electrical Material, 1943-46. V. The Corrosion of Copper Wires at D. C. Potential in Contact with Electrical Insulating Materials. R. J. Meakins. *Australian J. Applied Sci.,* **1,** 128-132 (1950) Mar.

Describes method for investigating the above under moist conditions. Results indicate that corrosion of this type depends chiefly on the affinity for water of the insulating materials with which the copper wires are in contact. Severe corrosion was observed in tests with cellulose materials, which are highly polar, whereas non-polar materials did not give corrosion.—BLR.

7.7, 6.4.2

Electrical Substations, A Growing Use For Structural Aluminum. A. M. Baker. *Modern Metals,* **6,** No. 4, 23-24, (1950) May.

The Pennsylvania Electric Co. of Johnstown, Pa., found it necessary to use aluminum in the construction of a substation during the war when there was a shortage of galvanized steel. Since then several other stations have been built of aluminum and more are anticipated. Although the initial cost of the aluminum is almost twice that of steel,

the saving on transportation costs, labor and maintenance almost compensate for the difference. The excellent weathering properties of aluminum are decidedly advantageous, especially where the atmosphere contains a high percentage of sulfur and corrosive gases. Aluminum does not require painting, which, besides eliminating the cost of the paint, eliminates the danger to workmen who would normally be engaged in painting near energized conductors. Aluminum towers and trusses can be factory-assembled where the members are joined by cold riveting using aluminum rivets of alloy 61S-T6, which have an ultimate shear strength of 30,000 psi. After delivery to the construction site, field erection is accomplished in about one-quarter the time required for steel structures.—ALL.

7.7, 6.4

Aluminum-Sheathed Cables. *Metal Industry* (London), **76**, No. 19, 389 (1950) May 12.

Conventional lead cable sheathing is being replaced by aluminum. The British Insulated Callender's Cables, Ltd. have several aluminum-sheathed cables on the market, the latest type being a 33 kv impregnated pressure cable manufactured in 330-yard lengths. The sheath of such a cable must withstand an internal nitrogen gas pressure of 200 psi. External steel reinforcement is required if lead is used, but is unnecessary with aluminum. The wall thickness of the aluminum sheath will not be less than 90 percent of the corresponding lead sheath. Corrosion tests on aluminum sheathing in both acid and alkaline soils have proved that the normal rubber bitumen sandwich serving offers adequate protection. Reinforcing tapes and the cast plumb are omitted with a resulting saving on cost and joining time. Improved techniques enable pressure of 1000 psi to be withstood for long periods without failure. The two methods of applying the aluminum sheath which are most developed are seamed aluminum tube (welded) and died-down sheath. The latter method has been adopted as the only practical means available for producing a seamless sheath. It consists of drawing the cable into an oversized tube; then both cable and tube are pulled through a "sinking" die which reduces the outside diameter to the required figure.—ALL.

7.8 Wires and Cables (Non-Electrical)

7.8, 5.5

Notes on Wear and Abrasion in Wire Ropes. *Mining J.*, **234**, No. 5987, 518 (1950) May 19.

Frictional wear, external and internal, cannot be entirely avoided, but it is minimized by frequent rope lubrication. Corrosion in moist atmospheres is prevented by lubrication but this is not effective if a hydrated rust coat is already present. Heavy oil should be applied warm for greater penetrability. Rate of wear is determined by the degree of lubrication and abrasion, sheave alignment, rope pressure and variations in rope pitch.—INCO.

7.8

An Alternate to Lead Sheath for Telephone Cables. A. Paone. *Corrosion,* **6**, No. 2, 46-50 (1950) Feb.

A new type of sheath was developed as an alternative to lead-antimony sheath for paper insulated exchange type telephone cables to permit rapid expansion of telephone cable production. A combination of corrugated aluminum, a flooding of moisture resistant cement and an outer polyethylene jacket provide moisture protection for the dry core. The new aluminum sheath, known as Alpeth cable sheathing, has been used extensively because lead production was not sufficient to keep pace with the core production. Properties of the aluminum cable include corrosion protection for use in conduit; it also affords a means of effecting distributed forced drainage to minimize corrosion on paralleling plain lead covered cables. Design considerations, field of use, method of splicing, and bonding arrangements are described.—ALL.

7.8, 6.2.2, 8.9.1

Cable Matches Expansion of Aluminum. *Aviation Week*, **53**, 32 (1950) Oct. 2.

Describes properties of steel aircraft control cable which expands and contracts at approximately the same rate as aluminum. "Hyco-Span," the new cable, is made by American Steel and Wire Co., Cleveland. Other important advantages claimed are nonmagnetic properties, excellent corrosion resistance, and simplified rigging and more positive control due to the cable's ability to expand and contract with the airframe. Data are shown graphically.—BLR.

7.10 Other

7.10, 6.3

Corroded Bronze. H. H. Symonds. *Metal Ind.*, **76**, No. 26, 505-506 (1950) June 30.

Premature failure of bronze retaining strip in a compensating assembly as fitted to the thermostat controlling gas temperature at a gas works necessitated a complete metallurgical examination, which showed that the assembly had come into contact with gases which were too corrosive for the material. Photomicrographs.—INCO.

7.10, 6.4

From a Metallurgist's Notebook: Corrosion of Aluminum. H. H. Symonds. *Metal Ind.*, **76**, 150, 152 (1950) Feb. 24.

Results of an examination of cast-aluminum kettle spouts which showed corrosion on the polished surfaces are discussed. The remedy is stated to be the production of sounder castings.—BLR.

7.10, 8.9

Corrosion Characteristics of Concrete River Clamps. *World Oil*, **128**, No. 10, 170 (1949) Feb. 1. *Corrosion*, **6**, No. 7, 38 (1950) July.

Unless the wrap of pipe line is doubled or trebled in the area covered by the clamp, the slight movement of the pipe will eventually break the coating on the edge of the weight, exposing bare metal in a narrow strip which sometimes extends one-quarter of the circumference of the line. Another failure is the formation of transverse fractures along lines of buried reinforced steel. The rust, being confined within the pores of the matrix material, cannot escape and swells eventually developing pressures which split the weights and can cause

breaks in tension of the bolts uniting the clamp halves.—INCO.

7.10, 5.4

Maintenance Painting of Steel Bridges. R. Mansell. *Am. Paint J.*, **33**, No. 46, 76, 78, + (1949).

The surface preparation and paint system used are described. A thorough wash down with a detergent is followed by a clean water wash and sand blasting an/or flame dehydration. The primer and undercoat are based on lead oxide and leafed metallic lead paste in raw linseed oil and the finishing coat on graphite in raw linseed oil and spar varnish. A special paint system which was used for repainting a bridge exposed to severe weather conditions consisted of a finishing coat based on white lead and zinc-oxide and, for spot-priming, a paint based on zinc dust and zinc-oxide.—RPI.

8. INDUSTRIES

8.1 Group 1

8.1.2, 5.3.2

The Protection of Steel Windows Against Rusting. *Architects J.*, **112**, No. 2898, 196 (1950) Aug. 24.

This short article points out the long term advantages to be gained from using window frames protected from corrosion by a zinc coating. Attention is drawn to B.S. 990 which specifies zinc coated window and door frames, and it is pointed out that there is no longer any shortage of available paint for treating the steelwork. Figures are quoted which show that the initial extra cost is more than recouped by savings in maintenance costs during the first 12 years alone.—ZDA.

8.1.2, 6.6.1

The Corrosion of Steelwork. S. G. Clarke. *The Builder*, **177**, 332-335 (1949) Sept.

An examination of two Liverpool buildings with badly corroded steel framework showed that corrosion can be prevented by 1) designing exteriors so as to hinder water penetration, 2) using dense concrete with an adequate cover in contact with the steel, 3) eliminating troublesome materials, especially breeze and clinker in concrete or mortars, and 4) applying paint or other protective coatings to steel encased in brick or stonework.—PDA.

8.3 Group 3

8.3, 7.5

Performance Factors in Filled Metal Containers. N. J. Willett and L. G. Germain. *Canner*, **110**, No. 1, 16-18 (1950); *Chem. Abs.*, **44**, No. 2659 (1950).

The more important factors affecting the performance of metal containers packed with food products are discussed. The problems treated include: internal corrosion, internal rusting, sulfide discoloration due to iron and copper contamination, corrosion due to sulfur and sulfur dioxide contamination, and external rusting.—MA.

8.3, 5.3

Some Aspects of the Corrosion of Tin Plate by Prunes. V. W. Vaurio. *Corro-*

uniting the

 sion, **6**, No. 8, 260-267 (1950) Aug.

Mechanism of the above corrosion was investigated. Evidence is presented which indicates that, in prunes at least, tin corrodes at a constant rate without the evolution of measurable quantities of hydrogen. Hydrogen evolution in canned prunes is related directly to the solution of the iron of the steel base. Shows that tin affords cathodic protection to steel in contact with prunes. These tests indicate that porosity is not an important factor. 11 ref.—BLR.

8.3.4, 6.3.10
Corrosion-Resistance of Nickel and Its Alloys in the Wine Industry. L. Arbellot. *Rev. Nickel*, **16**, No. 2, 29-40 (1950).

The uses and advantages of the following alloys of nickel for the construction of plant used in the wine and distilling industries are discussed: malleable nickel, Inconel, stainless steel, Monel, cupro-nickel, nickel silver and Ni-Resist cast iron. The results are given of some tests of the corrosion of the above alloys by the solutions handled in the production of wine.—MA.

8.3.3, 5.4.5
Coatings Against Corrosion and Deterioration. R. J. McMahon. *Food Inds.*, **21**, 758-759 (1949) June.

Corrosion and deterioration of equipment, floors, walls and ceilings of dairies and other food processing plants can be reduced by application of vinyl resin base plastic coatings. These coatings, developed to resist milk and its derivatives, also resist action by cleaners, sterilizing agents and moisture, and inhibit growth of bacteria and fungi. The coatings are available in baked phenolic form for high temperature applications, or as a liquid for spray or brush application for lower temperature exposure. A water dispersed pigmented coating has been developed for use in confined spaces, such as refrigerators, where solvent odors may be objectionable. Proper surface preparation is essential for successful coating application.—RA.

8.4 Group 4

8.4, 4.4
Corrosive Environments and Methods of Mitigation in Producing Sour Crude. D. A. Shock and J. D. Sudbury. *Oil Gas J.*, **49**, 73-74+ (1950) June 8.

Presents general discussion of the above in well, aqueous-hydrocarbon and vapor environments encountered in handling crude. Considers corrosion of K Monel, Inconel and high chromium-nickel steel equipment. 15 ref.—BLR.

8.4
Corrosion Problems in a Fluid Catalytic Cracking and Fractionating Unit. Nathan Schofer. *Corrosion*, **5**, No. 6, 182-188 (1949).

Most of the instances quoted are of the corrosion of ferrous metals, but brief mention is made of the performance of Admiralty metal condenser tubes. It is suggested that water raised to a pH of 8.0 with ammonia will not attack Admiralty metal in the presence of hydrogen sulfide, which acts as an inhibitor. —MA.

8.4, 1.7
Cures for Corrosion in Gas Condensate Wells. W. H. Stewart. *Petro. Eng.*,

22, Reference Annual Issue, B35-B38 (1950) July.

Reviews recent work on the above by various organizations including Battelle, U. S. Bureau of Mines, and University of Texas sponsored by NGAA and NACE.—BLR.

8.4, 5.2
Scale Deposit Prevention in Gas Lift Wells. R. B. Walter. *World Oil*, **130**, 228-230+ (1950) June.

Describes use of down-the-hole assemblies of zinc and copper to set up galvanic action to prevent scaling on the pump, tubing and other units of the flow string.—BLR.

8.4, 4.3
Tubing Corrosion Due to Hydrogen Sulfide, Accelerated by Spent Acid. J. G. Yapuncich. *Oil Gas J.*, **48**, No. 48, 68-69+ (1950) Apr. 6.

Describes and illustrates unusual condition of severe corrosion found in 8900 ft. Wyoming well.

Pitting and general corrosion on the inside of several joints of tubing at the swabbing fluid level were blamed on the action of the hydrogen sulfide, while that on the outside of the bottom joint was laid to the spent acid and hydrogen sulfide. Possible agents of corrosion in the field, as stray currents, formation water, hydrochloric acid, spent acid water, carbon dioxide and hydrogen sulfide and the effect of each is discussed. As long as the crude oil covers the metal surface, hydrogen sulfide corrosion is negligible. Active and severe corrosion will occur at and above the gas-oil contact, providing moisture is present to accelerate the attack. 6 references. Photographs.— INCO.

8.4.3, 3.5.8
Causes and Prevention of Drill Collar Failures. Stanley C. Moore. *Drilling*, **12**, 28+ (1950) Nov.

Discusses the above. Practically all drill-collar failures noted in the field are the result of fatigue at the connections —either simple fatigue in the case of the pins, or corrosion fatigue in the case of the boxes. Considers recommended operating procedures and design. Describes use of a magnesium ring in the drill-collar box to prevent corrosion in the bore near the ring, by electrochemical action.

8.4.3
Metallurgy in Petroleum Refining. D. A. Craig. Phillips Petr. Co. *Mines Mag.*, **40**, No. 10, 80-85+ (1950) Oct.

Metallurgy is discussed in regard to corrosion in the petroleum industry. Electrolytic corrosion, protective oxides, stress corrosion, intergranular attack, hydrogen action, welding, and use of metals at high and low temperatures are considered.

8.4, 3.4
Corrosion and Chemical Testing of Waters for Subsurface Injection. J. W. Watkins. *Producers Monthly*, **14**, 25-31 (1950) Apr.

Field methods are given for determining free carbon dioxide, hydrogen sulfide, pH of waters and brines, total and dissolved iron in water, alkalinity and carbonate stability, hardness, chlorides, residual chlorine and turbidity of waters used for water flooding. 20 references.
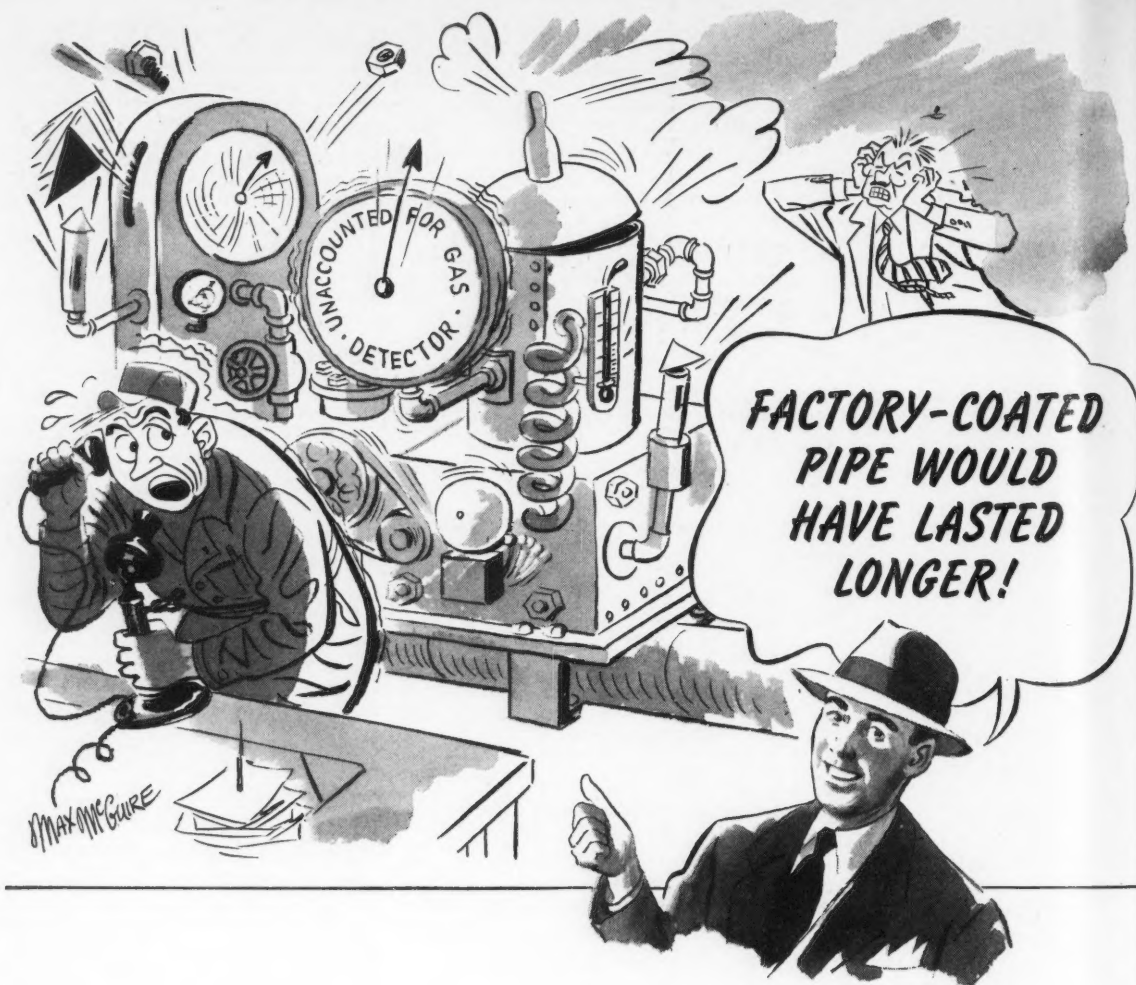
8.4, 5.4, 4.6
Protective Coatings for Offshore Rigs.

L. R. Whiting. *World Oil*, **129**, No. 8, 110-112 (1949); *Chem. Abs.*, **44**, No. 2, 852 (1950).

Surfaces of the offshore oil-well drilling platform are protected against the corrosive action of sea-water and the abrasive action of debris by surface coatings formulated from vinyl resins.— RPI.

8.4, 7.6
High-Pressure Vessels for the Oil-Refining and Chemical Industries. H. B. Fergusson. *Engineering*, **169**, No. 4385, 149-150 (1950) Feb. 10.—MI.

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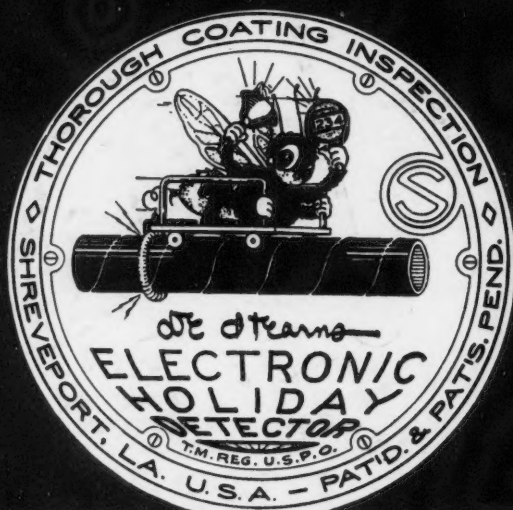
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